Preferred citation: P. Huber, T. Delagoutte, S. Ossard, D. Soysouvanh and P. Borel. A proposed link between machine runnability and stickies distribution within the sheet. In **Advances in Pulp and Paper Research, Cambridge 2013**, *Trans. of the XVth Fund. Res. Symp. Cambridge, 2013*, (S.J. I'Anson, ed.), pp 369–401, FRC, Manchester, 2018. DOI: 10.15376/frc.2013.1.369.

A PROPOSED LINK BETWEEN MACHINE RUNNABILITY AND STICKIES DISTRIBUTION WITHIN THE SHEET

Huber P., Delagoutte T., Ossard S., Soysouvanh D., Borel P.

Centre Technique du Papier, CS 90251, 38044 Grenoble, France
Corresponding author: Patrick.Huber@webctp.com

ABSTRACT

In recycled paper processes, stickies are at the origin of many production disturbances, such as machine breaks, defects in paper and converting problems. At the end of the recycling process, the most abundant and disturbing macro contaminants are fragments of pressure sensitive adhesives. These particles adhere to machines clothes, and clog the felts or even cause the break of the running paper web. The contamination is typically evaluated by measuring the total stickies concentration in the pulp after screening. However, industrial experience shows that it is difficult to correlate this stickies concentration with the occurrence of process disturbances. We suggest that only the amount of stickies that is effectively exposed at the surface of the sheet to the machine clothes is disturbing and is at the origin of runnability problems. In this work, we recall the definition of the stickies exposure, and use it to anticipate the effect of geometrical parameters on the fraction of stickies that are exposed at the surface of the sheet. Parameters such as stickies length and thickness, sheet thickness, or stickies orientation in the z-direction, are investigated. A new sensor is developed to characterise stickies in their 3 dimensions (without prior pressing), and discriminate them from other type of contaminants. Improvements compared to classical stickies measurements methods are discussed. The exposure of real stickies populations to machine clothes is measured in handsheets, and compared with results from the modelling.

INTRODUCTION

Environmental and societal concerns have favoured the use of recovered paper in larger volumes for paper productions. However, mills producing papers from recycled fibres very often face important troubles due to the presence of sticky contaminants associated with the incoming furnishes. Indeed, these materials, originating from glues, varnishes, coatings . . . included in recovered papers, are broken down during the recycling operations, giving rise to small and tacky particles called "stickies". Pulp contamination by stickies is responsible for many operational problems including: deposition at different positions in the papermachine (forming wires, press section, drying section, calender . . .) inducing many production disturbances (breaks, downtime for cleaning . . .), defects in the paper sheet (holes, spots), troubles during converting and printing (picking, clogging . . .) [1], [2], [3].

Recycling processes are designed to remove detrimental materials (ink, contaminants) and consequently include many different steps (screening, flotation, washing . . .) [4], [5], [6], which are supposed to lead to efficient elimination of stickies among other contaminants. To complement these physical treatments, chemical additives may be added to the pulp or process water to reduce stickies detrimental consequences. A review of these treatments is given in [7]. However, in spite of dramatic progresses achieved in the deinking technologies, mills still face stickies problems having strong detrimental consequences on their productivity [8], [9]. Moreover, these troubles tend to increase for several reasons: growing of adhesive usage in paper and board, reduction of recovered paper quality because of high demand, reduction of fresh water consumption . . .[10].

Many different products, used as paper additives, are at the origin of stickies formation. They are reported in various papers [11], [12], [13]. Nevertheless, adhesives materials are considered as one of the major and most detrimental source of stickies. Moreover, a large variety of adhesives materials can be found in papers and boards: pressure sensitive adhesives (labels, tapes, stickers . . .), adhesives for closing cartons and folding boxes, fixing elements for transportation, adhesive backs (books, catalogues, and magazines) . . . Hence, depending on their chemical nature, the behaviour of adhesives films during paper recycling will largely differ, giving rise to different sorts of stickies particles. A stickies classification is now well admitted including: macro-stickies (macroscopic particles larger than 100µm), micro-stickies (tacky objects from 1 to 100µm) and colloidal stickies (stickies particles having colloidal size and behaviour). A good description of this classification is given in the following papers [10], [14], [15], [16].

Concerning macro-stickies generation, pressure sensitive adhesive (PSA) films are considered as the most detrimental products. Indeed, in spite of some efforts to make adhesive films more resistant to fragmentation and therefore more easily screenable [17], [18], [19], these materials are most of the time broken down during paper repulping giving rise to small and soft particles usually very difficult to screen out of the pulp [20], [21], [22]. As a consequence, at the end of the recycling process most of the macro-stickies remaining in the pulp are PSA particles, stickies particles of other natures being much more efficiently removed [23]. In addition, these PSA stickies are strongly tacky at all process temperatures which makes them extremely harmful for the papermachine.

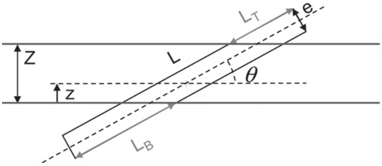
To quantify macro-stickies in a pulp, several methods were developed. Some methods are based on the counting of tacky objects in handsheets (handsheet inspection methods), some others isolate stickies particles by a screening step, which enables to concentrate them prior to counting [15], [24]. More recently, a macro-stickies sensor was developed by Ricard et al. [25] which enables online characterisation of stickies particles, after isolation, by optical means. Near Infrared Spectroscopy (NIR) was also investigated as a way to quantify stickies in pulp sample [26] [27]. Nevertheless, among these methods, the most common and currently recognized in Europe is the INGEDE#4 method. Its principle is based on contaminants isolation by pulp screening followed by measuring their size distribution over a paper filter. Tacky particles (stickies) are then specifically coloured and quantified by image analysis. Stickies concentration is given in particles number and area per dried pulp weight (e.g. mm^2/kg of pulp). This approach gives a good estimation of the macro-stickies concentration of a pulp sample, but mill experience often shows that a clear relationship between this concentration and paper machine stickies-related problems is not established [8], [28]. In some cases high contamination does not necessarily lead to production disturbances, while in other situations a limited stickies contamination causes important clogging and frequent breaks. Various phenomena may explain these situations, such as involvement of stickies categories not detected by the macro-stickies quantification method (micro or colloidal stickies) [7], [28], [29], [30]. Nevertheless, a possible alternative not explored until now, which derives from the stickies "damage potential" concept discussed in [31], states that both stickies "size" and "position in fibre network" determine the "tendency to form deposits". Indeed, depending on these parameters, macro-stickies will be more or less exposed at the surface of the paper sheet, which will affect their ability to be picked-up by the papermachine clothes. As a consequence, we have recently suggested that only the amount of stickies that is effectively exposed at the surface of the sheet to the machine clothes is disturbing and at the origin of runnability problems. Thus, based on this concept, we have proposed to correct the usual macro-stickies concentration in the pulp (mm^2/kg) by calculating the fraction of stickies surface which is actually in contact with papermachine clothes. This approach has allowed the calculation of a "stickies exposure index" which describes the amount of stickies effectively exposed to the wire and felts [32].

The objective of this work is to quantify the amount of stickies exposed at the surface of handsheets, resulting from the distribution of a stickies population within the sheet thickness. In this work, we recall the definition of the stickies exposure, and use it with model objects, simulating stickies, to anticipate the effect of geometrical parameters on the fraction of stickies that are exposed at the surface of the sheet. Parameters such as stickies length and thickness, sheet thickness, or stickies orientation in the z-direction, are investigated. To validate simulation results, trials with real stickies were carried out. Nevertheless to feed the "stickies exposure index" calculation, real stickies morphology parameters are needed (length, width and thickness). Existing stickies measurements techniques do not provide such information: INGEDE#4 method causes a change of the stickies shape as they are pressed and dried several times during preparation. Moreover, only two dimensions measurements (length and width) are provided. Recently a macro-stickies sensor was developed by Ricard et al. [25], this equipment enables the characterisation of the stickies particles, after isolation, by optical means without any pressing step and therefore no shape modification. However, only length and width of the objects are provided with this device. To overcome this issue we have developed a new sensor which characterises stickies in their 3 dimensions (and without prior pressing), and discriminate them chemically from other type of contaminants. Based on data obtained from this equipment, the surface of stickies that will be exposed to machine clothes is measured, and compared with results from the modelling.

THEORY

Definition of stickies exposure

We consider a cuboid stickies object of length L, width w and thickness e, buried in a sheet of thickness Z at depth z, with orientation θ (relative to sheet plane, rotations around other axes are less likely, and not considered) (Figure 1). The fraction of stickies surface which is exposed and visible at the surface of the sheet primarily depends on protruding lengths L_B and L_T on both sides of the sheet.



$$L_B = \min\left(\max\left(\frac{L}{2} - \frac{z}{|\sin(\theta)|} + \frac{e}{2|\tan(\theta)|}, 0\right), L\right)$$

$$L_T = \min\left(\max\left(\frac{L}{2} - \frac{Z - z}{|\sin(\theta)|} + \frac{e}{2|\tan(\theta)|}, 0\right), L\right)$$

Figure 1. Definition of the geometry of the stickies exposure problem (left) and expressions of protruding lengths L_B and L_T exposed on the bottom and the top of the sheet respectively (right).

The stickies exposure E is defined as the overall fraction of exposed stickies surface relative to total stickies surface (= Σ $((L_B + L_T)w)/\Sigma Lw$), and can be expressed by integration over all possible stickies length, width and thickness, for all possible stickies orientation and depth:

$$E = \frac{1}{\pi Z \bar{L} \bar{w}} \int_0^Z \int_{-\pi/2}^{\pi/2} \int_0^\infty \int_0^\infty \int_0^\infty (L_B + L_T) w f_L(L) f_w(w) f_e(e) g(\theta) h(z) dL dw de d\theta dz, \quad (1)$$

where $f_L(L)$, $f_w(w)$ and $f_e(e)$, are stickies length, width and thickness distributions respectively, $g(\theta)$ is the orientation distribution, and $h(z)$ is the depth distribution.

Then the specific exposure relative to paper surface can be calculated (E_S in m^2 of exposed stickies surface relative to m^2 of paper surface, considering both sides of the sheet):

$$E_S = \frac{1}{2} ECG, \quad (2)$$

where C is the stickies concentration of the pulp in (m^2/kg) and G is the sheet grammage in (kg/m^2). The factor ½ arises from the fact that concentration C is counted on one side of stickies objects (as classically performed in the standard stickies concentration measurement method, such as INGEDE method #4), while paper surface is counted on both sides of the sheet.

We have proposed that break phenomena on the papermachine could be better linked to specific exposed surface of stickies E_S, which may be picked up by the machine clothes, rather than to whole stickies concentration in the pulp C only. Note that the proposed concept of specific exposed surface of stickies E_S directly builds on the classical stickies concentration C, only corrected by exposed fraction E and sheet grammage G.

An in-depth discussion of the stickies exposure concept can be found in ref. [32]. The main conclusions are summarised hereafter, for better understanding of the present experimental results.

Stickies with uniform orientation distribution

For stickies population with uniform orientation (and zero thickness, constant length and width, and uniform depth distribution), the stickies exposure index E can be expressed as (see derivation in the Annexe):

$$\begin{cases} \lambda \leq 2, E = \dfrac{\lambda}{2\pi} \\ \lambda > 2, E = \dfrac{1}{2\pi\lambda}\left(-2\log\left(\dfrac{\lambda+\sqrt{\lambda^2-4}}{\lambda}\right)+2\log\left(\dfrac{\lambda-\sqrt{\lambda^2-4}}{\lambda}\right)\right. \end{cases}$$

$$\left. -\lambda\sqrt{\lambda^2-4}+\lambda^2-4\lambda\sin^{-1}\left(\frac{2}{\lambda}\right)+2\pi\lambda\right) \tag{3}$$

Where $\lambda = L/Z$ is the dimensionless stickies length, relative to sheet thickness.

The analytical expression of E (eq.3) shows that the contamination which is actually exposed to machine clothes depends mainly on the stickies length to sheet thickness ratio λ. The exposure E tends to zero for stickies which are small (compared to sheet thickness, i.e. $\lambda \to 0$). On the other hand, the exposure E tends to 1 for long stickies (compared to sheet thickness, i.e. $\lambda \to \infty$). Note that for stickies which have a given thickness ($e \neq 0$), the limit exposure for very long stickies is higher than 1, as some part of the stickies can be exposed on both sides of the sheet. The exposure E cannot exceed a value of 2 (for very long and thick stickies).

If we now set the length of stickies, we can study the effect of varying sheet thickness (or grammage) for a given stickies population. The fractional stickies exposure E is found to decrease with sheet thickness, as a larger fraction of the stickies population gets buried within the sheet (Figure 2, left). Thanks to the stickies exposure approach, it is possible to correct the total stickies concentration in pulp to estimate the amount of stickies effectively exposed. For instance, with stickies having a length of 0.5 mm and a sheet of thickness 100 μm, we calculate that only 60% of total measured concentration in the pulp is actually exposed to machine clothes when forming the sheet (with uniform orientation and depth distribution). In other words, a large proportion (about 40%) of total stickies surface is fully buried in the thickness of the sheet and consequently not “visible” anymore at the paper surface (especially for high grammage sheets).

On the other hand, the specific exposure E_S increases with sheet thickness and rapidly tends to a plateau value (when $L/Z < 2$, see Figure 2, right). This plateau value corresponds to the linear part of the expression of E. To explain this effect, we consider a constant surface of contaminated paper, and increase the sheet

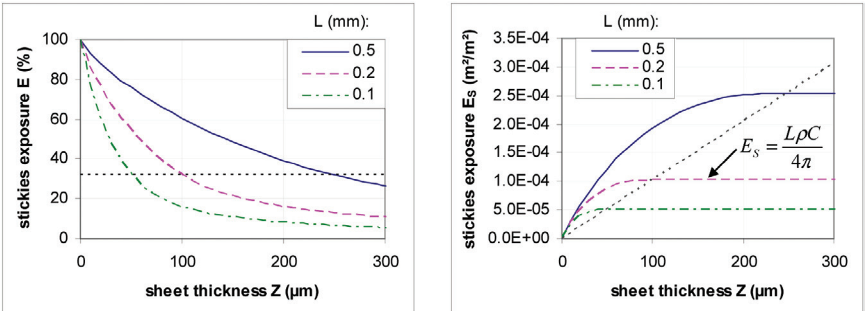


Figure 2. Stickies exposure vs. sheet thickness Z for various stickies length L (exposure of the stickies population E(%) (left), and relative to sheet surface E_S(m^2/m^2) (right) (stickies with thickness e=0, uniform orientation distribution, uniform depth distribution, the dotted line corresponds to $L/Z = 2$).

thickness (at constant stickies concentration). If we start with an extremely thin sheet, there is very little amount of stickies per unit surface of paper (as very little contaminated pulp has been used), so that the specific exposure E_S tends to zero. As the sheet thickness is increased, more pulp and more stickies are brought in, so that the exposure E_S increases. However, as the sheet thickness increases, the stickies are more likely to be buried in the sheet (according to the decrease of E), so that the rate of E_S increase is diminished. At some point ($L/Z = 2$), the 2 antagonistic effects of (i) stickies amount increase and (ii) exposure decrease, cancel out each other, and the specific exposure E_S tends to the plateau value (i.e. (i.e. $E_S = \frac{L\rho C}{4\pi}$ for $L/Z < 2$). This corresponds to the situation where the contaminated sheet of paper becomes homogeneous in the z-direction with respect to stickies contamination. In other words, if we make a sheet thicker than $L/2$, the exposed or visible stickies surface at the surface of the sheet will be constant. If the sheet is thinner than $L/2$, the exposed stickies surface will decrease with sheet thickness. These findings suggest that in certain conditions, grammage variation may substantially change specific surface of exposed stickies, for the same incoming stickies population. Thus changing grades towards higher grammage may increase stickies related problems on the papermachine, for light weight grades mostly.

It is also apparent from the expression $E_S = \frac{L\rho C}{4\pi}$, that longer stickies cause a larger specific exposure in thick sheets, at comparable stickies concentration. The importance of stickies length in exposure phenomena however depends on the stickies orientation distribution.

Importance of the stickies orientation distribution

Clearly, the orientation of a given single stickies determines whether (and by how much) it protrudes from the surface of the sheet. Numerical simulations show that stickies orientation distribution indeed has a large impact on the exposure of the whole population (Figure 3). When stickies tend to be aligned with the sheet plane, their exposure is reduced, compared to a uniform orientation distribution. However, the trend is reversed when $Z < e$ (that is because aligned stickies in a very thin sheet will have a higher probability of being exposed on both sides of the sheet).

Measurements of orientation distribution for stickies dispersed in handsheets are presented later on. We also anticipate that stickies orientation may depend on formation parameters on the papermachine, such as jet to wire speed ratio. Presumably, stickies would tend to be more aligned with the sheet axis in either a drag or rush formation regime, but that remains to be measured.

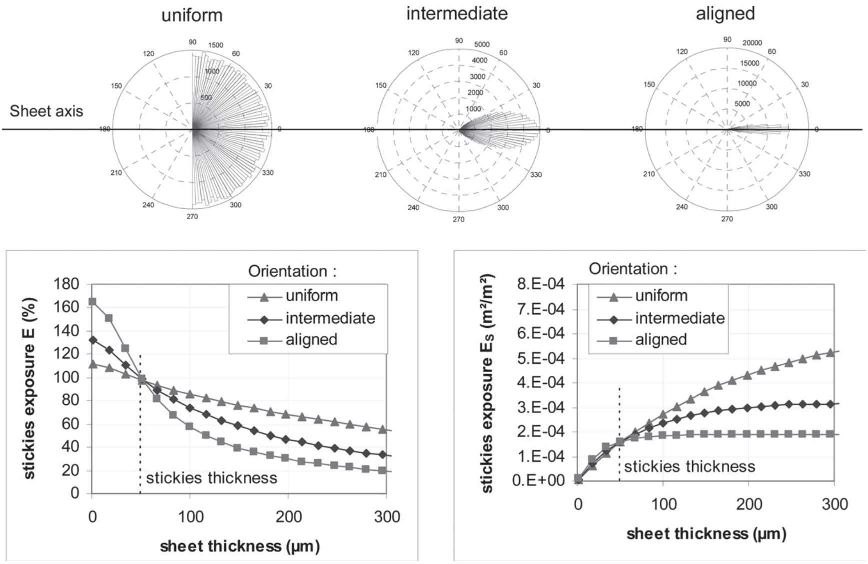


Figure 3. Effect of stickies orientation distribution on stickies exposure as a function of sheet thickness Z, expressed in % of total stickies concentration E(bottom left) or relative to paper surface E_S(m^2/m^2) (bottom right), orientation distribution of the stickies population (top row). Parameters of the numerical simulation: constant stickies length L = 1000 µm, constant width w=200 µm, constant stickies thickness e = 50µm, sheet density ρ = 640 kg/m^3, stickies concentration C = 10000 mm^2/kg.

In the limit case where all stickies are aligned with the sheet plane, we can derive the analytical expression of the exposure as well (see the Annexe)

$$\begin{cases} e < 2Z, E = e/Z \\ e \geq 2Z, E = 2 \end{cases} \tag{4}$$

This shows that the exposure does not depend on stickies length anymore for stickies which are all parallel to the sheet plane. The exposure is only determined by stickies thickness relative to sheet thickness. We can define a new dimensionless stickies size λ' for this particular case $\lambda' = e/Z$, which governs stickies exposure E

$$\begin{cases} \lambda' \geq 2, E = 2 \\ \lambda' < 2, E = \lambda' \end{cases} \tag{5}$$

The expression of the specific exposure relative to sheet surface E_S can be readily calculated

$$\begin{cases} \lambda' \geq 2, E_S = \rho ZC \\ \lambda' < 2, E_S = \frac{1}{2}\rho eC \end{cases} \tag{6}$$

For thin stickies or thick sheet (λ' <2), the exposure E increases proportionally to the stickies thickness e. As the stickies gets thicker (compared to the sheet), they have higher probability to protrude from the sheet surface. For very thick stickies, the exposure is constant and equal to 2, as the stickies will fully protrude on both sheet sides of the sheet. The transition arises when the sheet thickness is equal to half of the stickies thickness ($\lambda' = 2$, i.e. $Z = e/2$, with the hypotheses that the center point of the stickies is always within the sheet thickness). This shows that for stickies which are all aligned with the sheet plane, it only takes a small grammage for the sheet to become homogeneous in the z-direction with regard to stickies (Figure 4). Indeed, as stickies are expected to be relatively thin (in the range of 30–50 µm, see measurements later on) the plateau value for E_S (where E_S is independent on sheet thickness) is reached for low sheet thickness in this limit case (15–25 µm, which corresponds to a grammage of 7.5 to 12.5 g/m^2 for a sheet with bulk = 2 cm^3/g).

Comment on stickies depth distribution

The above analytic expressions E of (eq.3 and 6), assume that stickies are uniformly distributed within the thickness of the sheet. The numerical modelling

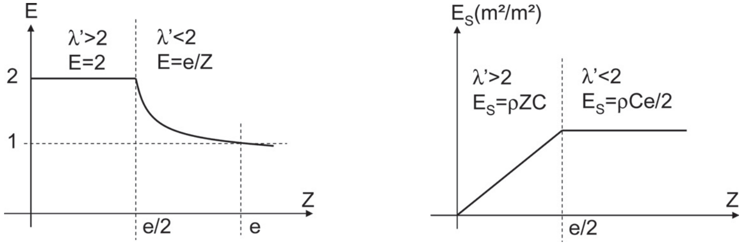


Figure 4. Stickies exposure vs. sheet thickness Z for stickies all parallel to the plane of the sheet (exposure of the stickies population E (%) (left), and relative to sheet surface E_S (m^2/m^2) (right) (stickies with thickness e, orientation parallel to the sheet plane, uniform depth distribution). Note that the curves given in Figure 3 converge to these limit trends for fully aligned stickies.

allows taking into account non-uniform depth distributions. This situation may arise in the case where different type of stickies may float or sink during sheet formation (the variable buoyancy of stickies dispersed in water has been clearly reported in ref. [33], however it remains to be checked if stickies may migrate through the sheet in the forming section of a papermachine). This would cause the exposure to be larger on one side of the sheet, and could either enhance or reduce deposit problems on modern board papermachines equipped with single-tier drying sections. Depth distribution data for stickies in laboratory handsheets are presented later on.

Stickies exposure in brief

To summarise, stickies exposure is related to both stickies morphology, sheet parameters, and distribution of stickies within the sheet (both in terms of depth and orientation). Long stickies (compared to sheet thickness) will be largely exposed to papermachine clothes, and may therefore cause more frequent runnability problems (at a given stickies concentration). Preferential alignment of stickies with the plane of the sheet causes the exposure of the stickies population to decrease. In this case, the thickness of stickies becomes more important than their length in exposure phenomena. Also, for typical sheet thickness of tissue or newsprint grades, increasing the sheet grammage is expected to increase the exposed stickies surface relative to sheet surface. For thicker sheets (board grades), the specific exposure relative to paper surface is independent of sheet grammage.

There is very little information in the literature about the 3 dimensional morphology of stickies (as they are usually characterised in 2 dimensions after pressing). Estimation of stickies exposure therefore requires new experimental technique, and a dedicated sensor is presented in the following.

It should be emphasized that stickies deposition is a complex problem, where geometry (which governs the exposure of stickies) is only one aspect. It is believed that an exposed stickies is only the necessary condition for the deposition on machine clothes to occur. Then adhesion phenomena will determine whether the exposed stickies may stick to the clothes or not. Also, in order to predict break phenomena, the internal strength of the web should be taken into account, as a weak sheet may be disrupted by the pick-up of a single (and small) stickies, while a stronger sheet may endure multiple detachments of (possibly large) stickies. We propose that the concept of stickies exposure is only the first step towards a more comprehensive approach of stickies related problems on the papermachine.

EXPERIMENTAL METHODS

Preparation of stickies from industrial recycled pulp samples

Pulp samples were taken along an industrial deinking line, using a variety of wood-free recovered papers (samples taken in the coarse screening area). The samples were firstly enzymatically digested (cellulases, see ref. [34] for conditions), then screened (Somerville, 0.1 mm slots, 25 g, 20 min). The rejects are deposited on a filter paper, for further conventional characterisation (INGEDE #4 method) or new 3D characterisation as proposed in this work.

Preparation of model stickies

Model stickies were prepared with rolls of label (PSA adhesive, E115 Jackstadt, 3.5% on pulp) laid on bleached hardwood kraft pulp sheet (BHKP) and pulped in a Helico pulper (10%, 20 min, 45ºC). After screening, model stickies were collected on filter paper for characterisation or used for further contamination of handsheets.

Black stickies

This population of model stickies has been used to characterise the stickies depth and orientation distribution within the sheet thickness (through reflected light measurements, see later). The adhesive film was pressed with carbon black (Prolabo Ref. 26005.296, [34]), before repulping. The contaminated pulp was then screened with a Weverk (0.15 mm slots, 10 1/min, 100 g, 30 min), then the accepts were screened on a Somerville (0.1 mm slots, 25 g, 20 min). The stickies population consists of rejects of the Somerville screening.

White stickies

In order to determine the exposure of a stickies population within a handsheet, a second model stickies population has been prepared without carbon black (called "white stickies"). In order to have a large stickies concentration and high sensitivity in the image analysis measurement, another procedure was used. The contaminated pulp was directly screened on a Somerville (0.1 mm slots, 25 g, 20 min), and the rejects were collected. This gives a stickies population with larger objects that are more likely to protrude out of the sheet.

Characterisation of stickies

Conventional characterisation of stickies (INGEDE #4 method)

The principles of the INGEDE #4 method ("Analysis of macrostickies in pulps") are quickly recalled, in order to point out the differences with the new proposed 3DStick method. The filter with the contaminants particles is covered with non-stick silicone paper, then dried on a Rapid-Köthen device (10 min, 94 ºC, pressure of 95 kPa). This step causes the sticky particles to strongly adhere to the filter paper. They are also pressed and deformed subsequently. The silicone paper is then released and non tacky contaminants are removed from the surface with a soft brush. The filter is then completely dyed through immersion in a black ink bath. The dyed filter is dried on a Rapid Köthen between 2 silicone papers (same conditions as before). Then the stickies particles are revealed with a white alumina powder. The powdered filter is then pressed and dried again, and excess white powder is removed with a soft brush. This leaves only white stickies particles on a black background. Stickies are then counted and characterised on a desktop scanner with standard image analysis.

The INGEDE #4 method is the most popular standard to measure stickies in Europe. The North American TAPPI standard T277-om7 ("Macro-stickies content in pulp: the 'pick-up' method") is very similar, and differs only in the way of revealing the stickies after pressing (using a white coated paper which is picked by stickies instead of the white powder).

Characterisation of stickies in their native state (3DStick method)

Three-dimensional characterisation of the stickies population was performed with a dedicated laser triangulation device, called "3DStick", and specifically developed by CTP (Figure 5). Briefly, the stickies deposited on the filter are scanned with a red laser sheet illumination. A visible CCD camera (2048 pixel field width) placed at 90º (triangulation principle), analyses the deformation of the projected laser line caused by the presence of a stickies object. As the couple laser/camera

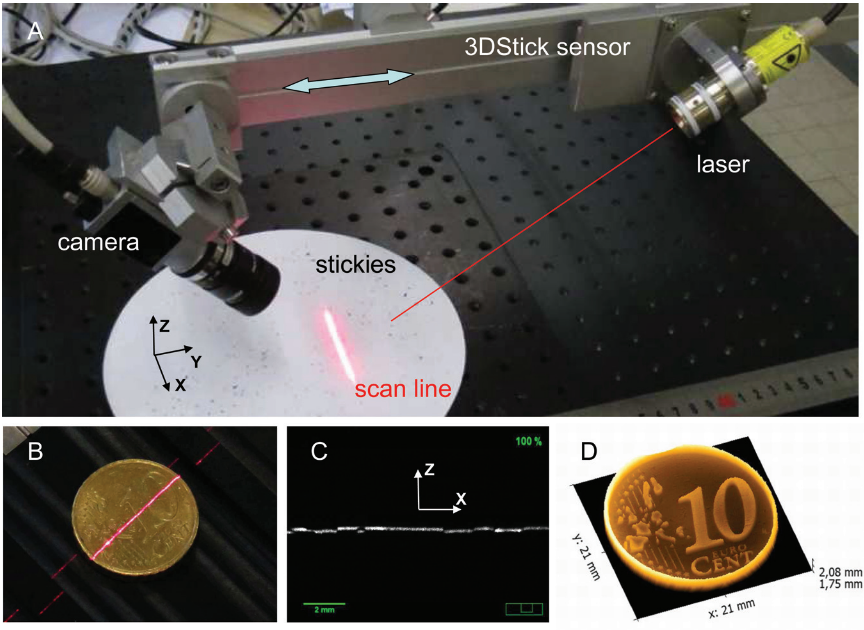


Figure 5. CTP laser triangulation device (3DStick) for stickies characterisation (A), example of profile scanning with a coin (B), detected scan line (C), and reconstructed altitude model (D).

is moved horizontally relative to the filter paper, all profiles scanned can be stacked in order to reconstruct a 3D image of the surface of the filter with all deposited stickies (resolution $dx = dy = 20$ µm, $dz \approx 3$ µm, see Figure 6). Each detected stickies is then analysed through blob image analysis. An equivalent cuboid object is identified (L x w x e), where length L corresponds to the major axis of the equivalent ellipsis, width w is calculated from the projected surface S of the detected stickies ($w = S/L$) and thickness e is calculated from the total volume V of the detected stickies ($e = V/S$). The uneven flatness of the free filter paper surface had been previously corrected through a Gaussian filtering. Thus, a 3D map of all the stickies can be reconstructed and stickies counts, lengths, widths and thicknesses may be statistically studied.

Identification of stickies among contaminants particles

When dealing with industrial samples of recycled pulps, the contaminants consist of various types of particles. In the case of deinking mills, they mostly consist of

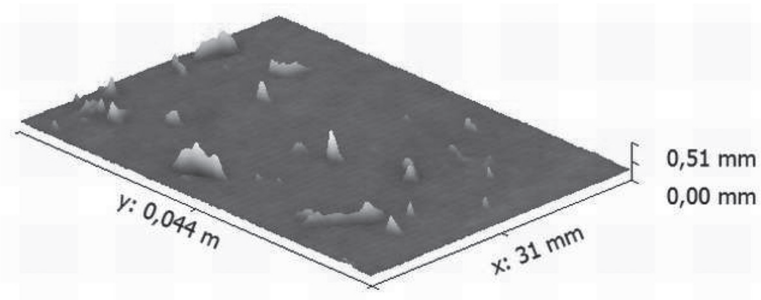
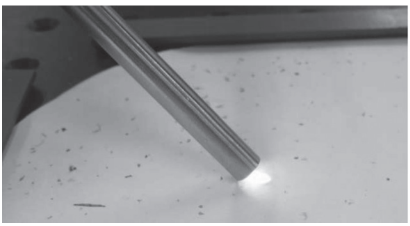


Figure 6. Example of reconstructed altitude map for stickies deposited on filter paper (z-scale has been enlarged for visualisation, flatness of filter paper corrected).

various fragments of plastics, adhesives, sand, glass, and metals [35]. In order to discriminate the stickies among the particles detected with the laser triangulation sensor, a near-infrared (NIR) spectroscopy method was used. After particles detection and localisation on the filter paper by the 3DStick device, a NIR probe was used to assess the chemical nature of each detected object. This allowed discriminating the stickies from other contaminants without any contact (therefore causing no deformation).

The NIR spectrometer has a spectral range of 1103 to 2197 nm, with 256 channels and an integration time = 4 ms. The analysis probe consists of a bundle of optical fibres, with an outer crown of 6 illuminating fibres (connected to a collimated halogen source), and a core for analysis of back-scattered light with the spectrometer. The analysis probe was used with an angle of about 45º with the vertical, to minimise specular reflections from the illuminating source (Figure 7, left). For each detected object the NIR spectrum was acquired, and then the object was tested for tacky character with a needle under a binocular (as in the historical



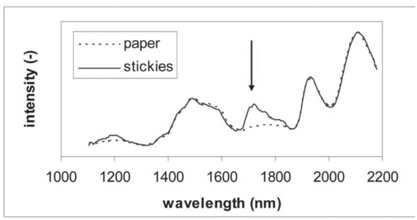


Figure 7. (left) Picture of the NIR spectroscopy probe set-up and (right) example of spectrum typical of an industrial stickies particle deposited on filter paper (characteristic band of adhesives is clearly visible).

stickies characterisation method). We have found that nearly all particles with tacky behaviour show a distinct NIR spectrum with a characteristic band (ranging from about 1660 to 1740 nm, see Figure 7, right). This was the final criteria for deciding whether an object could be considered as a stickies or not (as the aim here is to develop a non-contact characterisation method). Similar spectra were observed for the PSA adhesives laid on paper used for the model stickies populations. The same wavelength band has been proposed in refs [26] [27] for detection of stickies in handsheets with a hyper-spectral NIR camera.

In this study, the NIR characterisation of deposited contaminants has been performed manually. However, the measurement method has the potential to be fully automated. Typical chemometrics analysis of the NIR spectra will provide a sorting of contaminants within relevant categories (stickies, other plastics, cellulosic shives, metals, etc.). Thus a sensor for 3D characterisation of the contaminants together with their chemical nature will be available in the near future.

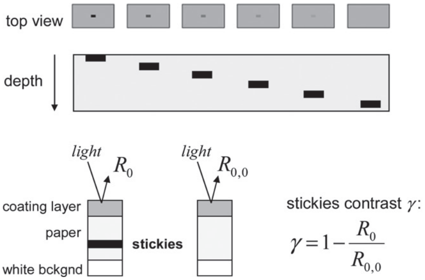
Contaminated handsheets

BHKP was disintegrated in a Helico pulper (10%, 20 min, 45ºC). Model stickies and pulp were mixed to produce a highly contaminated pulp. Handsheets of about 30, 50, 100, 200 g/m^2 were prepared on the Retention handsheet former (FRET, Techpap, France). The average bulk of the handsheets was 2.03 cm^3/g.

A first series of contaminated handsheets were prepared with the "black stickies" population (C = 30497 mm^2/kg, as measured with INGEDE method #4), in order to determine depth and orientation of stickies within the sheet. A second series of contaminated handsheets was prepared using the "white stickies" population (C =1.155×10^6 mm^2/kg, as measured with INGEDE method #4), in order to estimate the exposure of stickies at the surface of the sheet.

Depth and orientation of stickies within the sheet

In order to determine the distribution of stickies within the sheet, a Kubelka-Munk attenuation model was used (see [36] for full details). When black stickies are present at the surface of the sheet, their contrast against the sheet background is maximum. As the stickies are buried within the sheet, their surface contrast gets reduced (Figure 8, top left). The magnitude of this contrast reduction depends on the optical properties of the sheet (i.e. the Kubelka-Munk absorption coefficient k and scattering coefficient s). Black stickies are modelled by an ink layer within the base paper depth (see Figure 8, bottom left). The stickies contrast γ is calculated by a Kubelka-Munk multi-layer approach [37] [38]. This allows calculating the black stickies extinction curve (i.e. stickies contrast γ vs. stickies depth within the sheet, see Figure 8, right). The k and s coefficient at 457 nm of the handsheet were



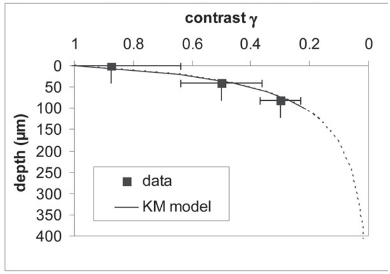


Figure 8. Kubelka-Munk attenuation model used to calculate object depth within the sheet from its measured surface contrast (sheet optical properties: k = 0.52 m^2/kg, s = 44.04 m^2/kg): (left) schematic of contrast calculation, (right) validation with handsheets having an embedded layer of black stickies at known depth (contrast at the top surface of stickies layer, vertical bar represents stickies layer thickness, horizontal bar represents standard deviation of contrast of all stickies within the layer).

calculated through measurement of brightness, and reflectance of single handsheets in conditions similar to those of the brightness measurement (spectrophotometer Colourtouch, Technidyne). The attenuation model has been validated with handsheets having an embedded layer of black stickies at known depth (multi-layer sheets made on the Dynamic handsheet former (Techpap, France), the stickies layer consisted of pulp + black stickies (163 000 mm^2/kg) equivalent to 20 g/m^2 dry grammage, the stickies layer depth varied from 0, 20 to 40 g/m^2, within the sheet total grammage of 200 g/m^2, see Figure 8, right).

The handsheets with black stickies (dispersed throughout the whole sheet thickness) were scanned on a desktop scanner in reflected light, using the same conditions as for the stickies detection procedure (Simpatic, Techpap, France, with pixel size=42 µm). The stickies detection method is illustrated in Figure 9. The gray levels in the image were converted to reflectance values R through a linear scaling (where the brightness value R_∞ of the handsheet background corresponded to the maximum gray level, and zero reflectance corresponded to the minimum gray level in the entire image). The contrast map C was calculated from $C = 1 - R/R_\infty$. The stickies were detected from a binary thresholding procedure (keeping only the objects with contrast >0.2 and having more than 10 contiguous pixels). The contrast map was then converted to a 3D depth matrix using the Kubelka-Munk attenuation model. This enabled to detect the upper boundary of the stickies object. The cloud of 3D points was fitted to an inertia ellipsoid (through singular value decomposition, svd.m function in Matlab). This gave the coordinates of the centroid of the ellipsoid and corresponding axes with rotation angles. The orientation θ of the stickies relative to the sheet plane was defined as

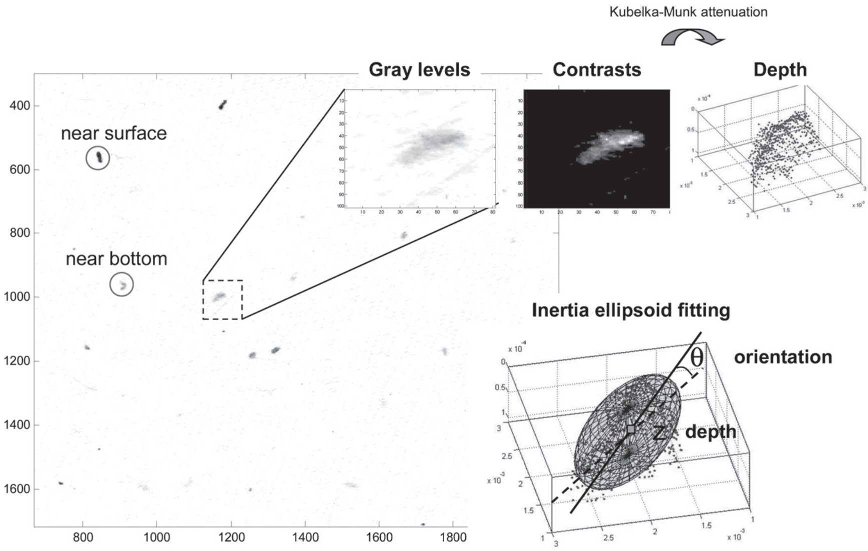


Figure 9. Methods for estimation of stickies depth and orientation within handsheets, based on constrast attenuation. This is an example of scanned handsheet with dispersed black stickies. All stickies are identically black, the deeper the stickies, the lower their contrast.

the second Euler angle of the rotation matrix. The stickies depth z was defined as the z-coordinate of the centroid.

Measurement of stickies exposure in handsheets

Handsheets contaminated with white stickies are dyed with black ink (Pelican Nº4001), dried, powdered with alumina powder and dried again. The whitened exposed surface of stickies is measured according to INGEDE method #4 with a desktop scanner system (Simpatic, Techpap, France). This reveals only the fraction of stickies exposed at the surface of the sheet.

Prediction of exposure for characterised stickies populations

The exposure for real stickies population (with distribution of their length, width and thickness, together with given orientation and depth distribution) was calculated through statistical simulations making use of (eq(1)). Briefly, the nested integrals were approximated by averaging the protruding length L_B and L_T for a large number of distributed objects, similarly to a Monte Carlo method, see ref [32] for details.

RESULTS AND DISCUSSION

3D morphology of stickies

The stickies isolated among recycled pulp contaminants are measured to be approximately 1000 µm in length, 350 µm in width and 25 µm in thickness (see typical distributions in Figure 10). The various stickies populations measured throughout coarse screening operations are found to have similar morphology (Table 1). To our knowledge, this is the first time that information has been collected about the 3 dimensional morphology of stickies. By comparison, data by 2D image analysis of screened contaminants before pressing from ref [25] show an equivalent disk diameter of 520 and 800 µm for heavy stickies and light macrocontaminants respectively for a SOW pulp (Sorted Office Waste).

Note that stickies account for only a fraction of total screened contaminants. The NIR probe was used to sort stickies among all contaminants detected by

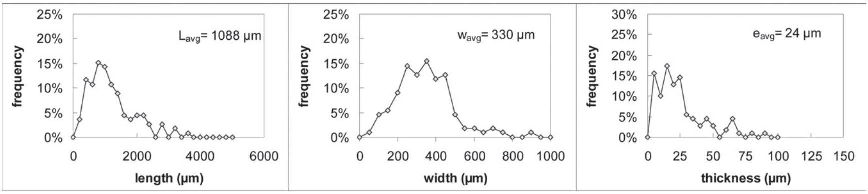


Figure 10. Example of length, width and thickness distributions measured in an industrial stickies population (n=112 objects, sample RP3). Objects were characterised by laser triangulation (3DStick device) and classified as stickies through NIR spectroscopy.

Table 1. Average morphology of various stickies populations measured with the 3DStick method (the measured morphology of model stickies illustrates that "black stickies" were prepared after a Weverk screening (hence their smaller size) while "white stickies" where prepared without (hence their larger size))

Stickies type	*Ref*	*Length (µm)*	*Width (µm)*	*Thick. (µm)*	*Number of stickies*
industrial	RP1	996	366	26	46
industrial	RP2	977	332	28	59
industrial	RP3	1088	330	24	112
model	black stickies	1074	338	29	513
model	white stickies	1980	464	46	380

laser triangulation, so that only the morphology of stickies is reported here. Nevertheless, we have found that other contaminants (plastics, ink specks and metals mostly) have morphology similar to stickies (average: length =1161 μm, width =327 μm, thickness =20 μm, example for sample RP3, n=144 objects other than stickies).

Thus the proposed technique allows characterising and measuring various types of contaminants. Three dimensional characterisation could be useful to better estimate and understand passage ratio of contaminants through pressure screens. The application of this technique to investigate screening efficiency in recycling lines is beyond the scope of this paper, and will be presented in a future publication.

Due to variable colour of industrial stickies, it was not possible to use them to study their distribution within the sheet. Hence, model stickies were prepared instead.

The black stickies population was prepared for the purpose of determining the distribution of stickies within the sheet thickness (see later). These black stickies characterised through the 3DStick sensor feature the following average morphology ≈ 1100 × 350 × 30 μm^3 (see distributions in Figure 11, A). Interestingly, their morphology is very similar to that of the tested industrial stickies samples. This probably results from the fact that the 0.15mm lab screen that was operated (Vewerk) mimics industrial pressure screens in some way.

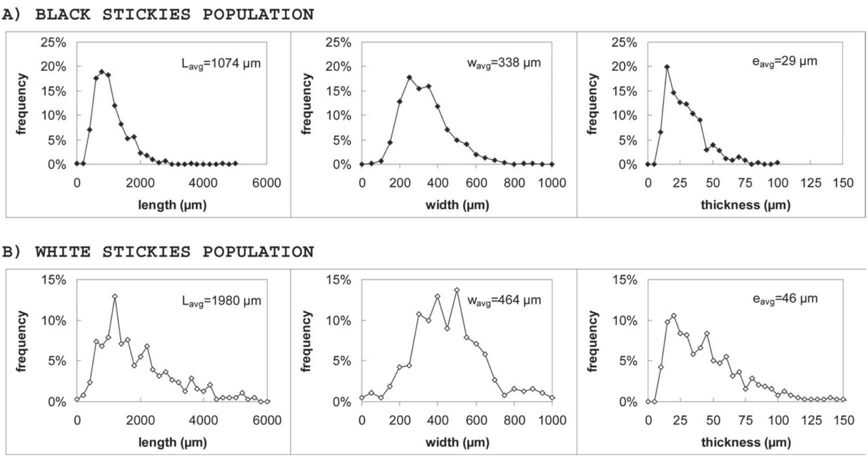


Figure 11. Length, width and thickness distributions measured in model stickies populations. Classification of stickies through NIR spectroscopy was not used on these model stickies populations, as it was assumed that all objects detected by laser triangulation were stickies.

Unfortunately, these black stickies cannot be used to determine the exposure at the surface of the handsheets, as they are not sticky enough to fix the white alumina powder used to reveal them (as the carbon black has passivated their surface).

So, the white stickies population was prepared for the measurement of stickies exposure in handsheets. As measured with the 3DStick sensor, the average equivalent cuboid stickies object for the white stickies population has following dimensions ≈ 2000 × 500 × 50 μm^3 (see distributions in Figure 11, B). These artificial white stickies are larger than those found in an industrial recycling process. Recall that this was made on purpose, in order to easily detect the exposed stickies in the handsheets. This also shows that both preparation and 3D characterisation methods for stickies are consistent.

Comparison of stickies measurement methods

The number of stickies objects counted with the 3DStick method (by a non contact method combining laser triangulation and NIR spectroscopy) was similar to the number of stickies obtained through INGEDE #4 method (by a sequence of drying/pressing, brushing, black dying, drying/pressing, white powder fixing, drying/pressing, 2D image analysis) (see Table 2, "Stickies count" and Figure 12). This means that all stickies were correctly identified among the various contaminants deposited on the filter, with the 3DStick method.

As already mentioned, the INGEDE #4 method modifies the morphological characteristics of stickies upon pressing. With the proposed 3DStick measurement method, stickies are characterised in their native state, without any pressing.

Table 2. Total stickies count and surface estimated with the 3DStick and INGEDE method #4 (the stickies surface concentration (mm^2/kg) in the 3DStick method is calculated as $C = (\Sigma Lw)/m$, where m is the mass of contaminated pulp used for screening)

		Stickies count		*Stickies surface*		
Stickies type	*Ref.*	*3DStick nb/kg*	*INGEDE #4 nb/kg*	*3DStick mm²/kg*	*INGEDE #4 mm²/kg*	*Spreading factor (–)*
industrial	RP1	11236	11197	5062	7510	1.48
industrial	RP2	7245	7689	2620	3378	1.29
industrial	RP3	13707	10536	5574	7006	1.26
model	black stickies	35863	32841	14165	30497	2.15
model	white stickies	343736	371416	361150	1155180	3.20

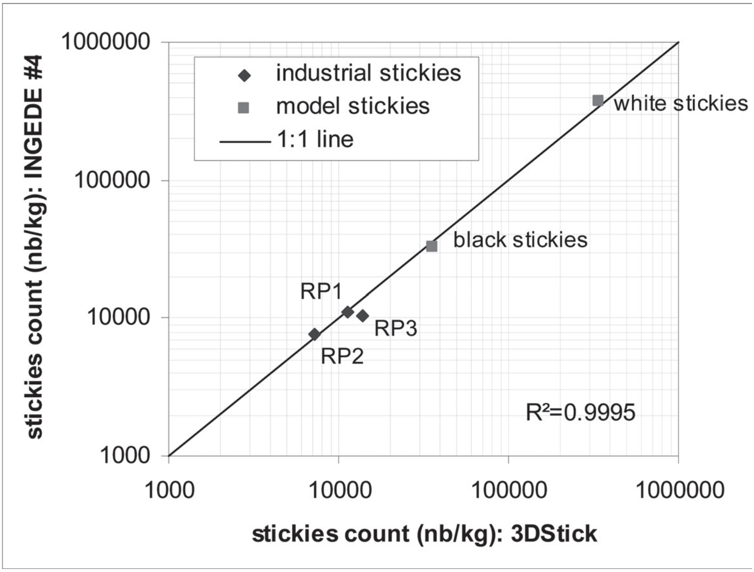


Figure 12. Comparison of stickies count detected by the 3DStick and INGEDE #4 method.

By comparison with stickies morphology in their native state, we have found that the INGEDE method #4 causes a spreading factor ranging from 1.26 to 1.48 for industrial stickies (Table 2, "Stickies surface").

The spreading factor for model white stickies was larger (= 3.2, see Table 2 "Stickies surface", and Figure 13). The difference of spreading behaviour under pressure may be explained by the fact that the model white stickies are much larger than the collected industrial stickies.

Distribution of stickies within the sheet

Depth distribution

The optical analysis of handsheets contaminated with model black stickies, reveals that stickies are uniformly distributed within the sheet thickness (Figure 14). That finding is valid whatever the grammage of the handsheet (tested from 50 to 200 g/m^2). The vacuum drainage that was applied on the FRET sheet former (400 mbar) is intended to reproduce drainage conditions of a (slow) Fourdrinier forming section. This did not affect the initial uniform distribution of stickies in the pulp to be dewatered (nor did that pull stickies towards the bottom of the sheet, neither did the stickies float to the surface). It remains to be

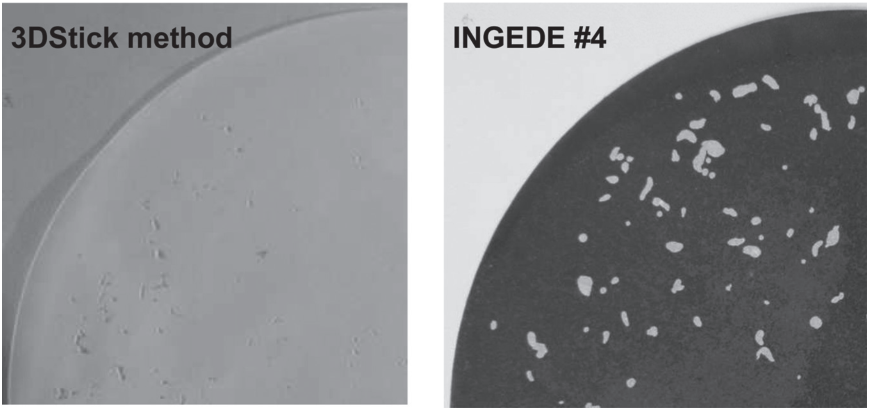


Figure 13. Comparison of stickies characterisation methods, (left): 3DStick method, model white stickies population stickies deposited on filter paper, to be characterised in their 3 dimensions with laser triangulation; (right): INGEDE method #4, stickies deposited on filter paper, pressed, whole filter dyed in black, stickies revealed with white powder, and to be characterised by their surface area with a desktop scanner analysis. The spreading of stickies caused by repeated pressing is clearly visible in the right panel.

checked whether this can be generalised to a forming section of a papermachine (Fourdrinier, or twin-wire with drainage on both sides of the sheet).

Orientation distribution

Besides, the stickies are found to be preferentially oriented in the plane of the sheet (95% of the stickies have an orientation comprised between –5º and +5º relative to the plane of the sheet). Their orientation distribution is rather independent on the thickness of the sheet (Figure 15).

Thus, the contaminated handsheets manufactured in this study feature a uniform distribution of stickies, which may be seen as platelet objects with their plate surface laying roughly parallel to the plane of the sheet.

Exposed stickies in handsheets

The exposed part of stickies objects embedded in handsheets is visualised in Figure 16. Interestingly, the exposed stickies in the 100 g/m^2 handsheet look very much like the stickies in their native state, as characterised by the 3DStick method. This confirms the potential interest of such a method to predict pick-up of stickies from machine clothes compared to the standard method. The state of the exposed

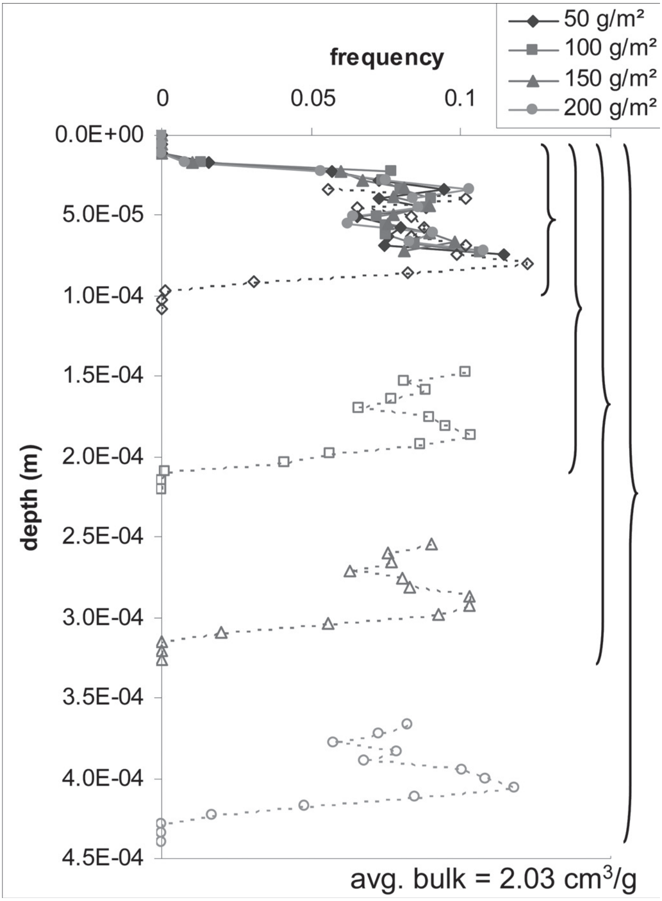


Figure 14. Depth distribution of stickies embedded within sheets (black stickies, virgin pulp handsheet, variable sheet grammage). Note that stickies can only be seen on the first 80µm of each side of the sheet, as their contrast is reduced below detection threshold deeper in the sheet. Also, stickies are not found in the first 10µm of the sheet, as the method identifies the center point of the stickies, which is necessarily below the surface.

stickies may however depend on the sheet grammage, or more exactly on the stickies size to sheet thickness ratio (see later).

Direct measurements of exposure for stickies embedded in handsheets, show that the exposed fraction of stickies population E decreases down to zero with sheet thickness, as predicted by the model (Figure 17, left). This confirms that only a small fraction of total contamination is exposed in high grammage sheets.

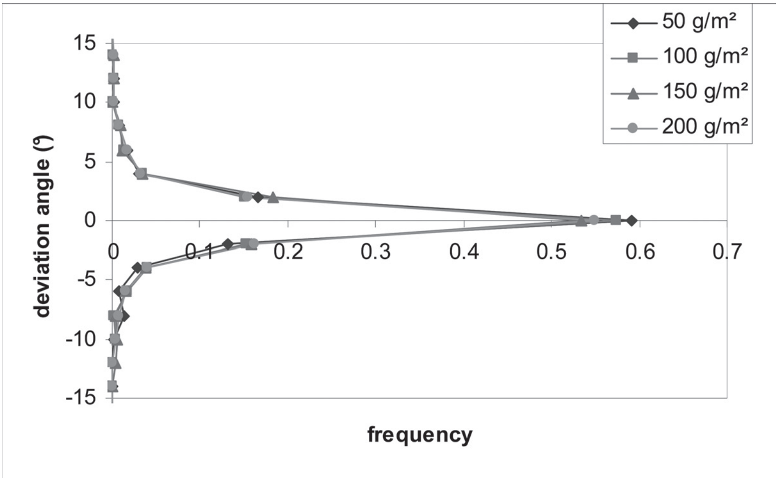


Figure 15. Orientation distribution of stickies embedded within sheets (black stickies, virgin pulp handsheet, variable sheet grammage). Again, it was not possible to identify the orientation for stickies which are in the centre of thick sheets, because of their low contrast.

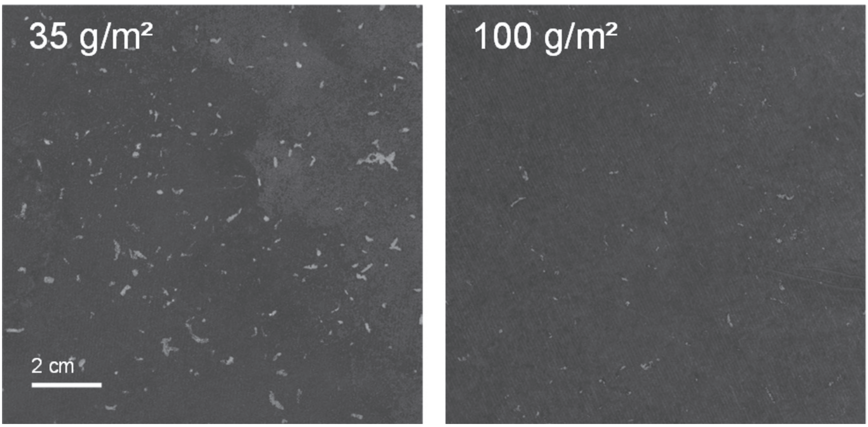
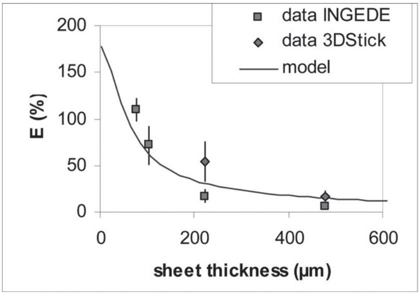


Figure 16. Observation of the exposed part of stickies embedded in handsheets, visible as white particles on a black background (the sheet has been dyed with black ink, and the parts of the stickies protruding at the sheet surface have picked-up the applied white alumina powder). The same stickies population has been used in both cases. Exposed stickies count is similar for both grammages. Deformation of protruding stickies part is apparent in the 35 g/m^2 handsheet.



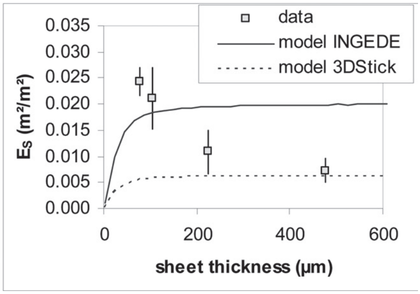


Figure 17. Comparison of measured and predicted exposure of stickies embedded in handsheets (average of the 2 sides). Only the exposed surface of stickies relative to paper surface (E_s (m^2/m^2) "data" in right panel) is directly measured (error bars represent the standard deviation of the measurements). The exposure of the stickies population E (%) in left panel is recalculated with $E = 2E_s/(CG)$ using either the stickies concentration C measured by the INGEDE method ("data INGEDE") or the 3DStick method ("data 3DStick"). The points "data 3DStick" for thin sheets correspond to exposure higher than 200% (not plotted), which is representative of deformation of stickies part protruding out of the sheet. The exposure E (%) "model" is predicted by the proposed modelling using the measured 3D morphology of the white stickies population, together with the measured depth and orientation distribution. The corresponding specific exposure E_s (m^2/m^2) "model" is calculated with either stickies concentration measured by the INGEDE method ("model INGEDE") or the 3DStick method ("model 3DStick"), together with sheet grammage.

On the other hand, the exposure relative to paper surface E_s is firstly thought to increase with sheet thickness, as the specific exposure is equal to zero for extremely thin sheets (since zero pulp brings zero stickies). The specific exposure E_s then falls down for large sheet thickness (and possibly stabilises to a plateau value, see Figure 17, right). The proposed modelling predicts the right order of magnitude for specific stickies exposure, E_s, calculated using the 3D stickies morphology data, measured depth and orientation distributions, and stickies concentration calculated from the same morphology data as $C = (\Sigma Lw)/m$ (where m is the mass of contaminated pulp used for screening). The predicted plateau value is consistent with the measured exposure in thick sheets. However, for thin sheets, the measured specific exposure is much higher than this predicted value. The proposed explanation is that, in a very thin sheet, the exposed fraction of stickies is protruding out of the sheet surface, and is flattened upon pressing of the handsheet. This would cause the increased exposed surface. That is corroborated by the fact that the measured number of exposed objects is found to be roughly independent on the handsheet thickness (Figure 18). In other words, if no deformation of protruding stickies had occurred, the specific exposure E_s would be

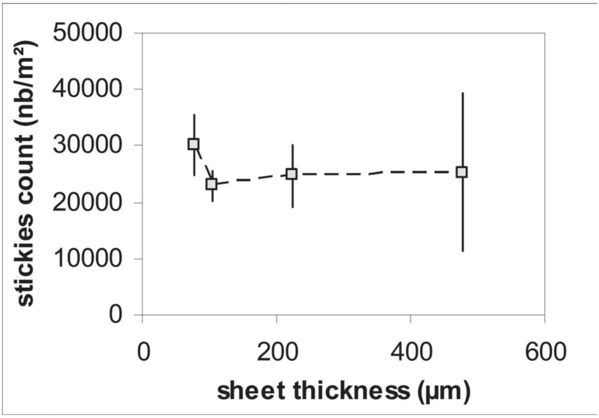


Figure 18. Number of exposed stickies vs. sheet thickness (average of the 2 sides, error bars represent the standard deviation of the measurements).

more or less constant, whatever the sheet thickness. On the other hand, in a thick sheet, there is limited protruding of stickies and therefore little flattening of exposed fraction of stickies. Visual examination of the thin handsheets (after blackening and stickies whitening) shows that exposed stickies look very much like stickies prepared on filter paper for measurement of pulp contamination through INGEDE method #4 after pressing (see Figure 16, left). By comparison with stickies morphology in their native state, we have found that the INGEDE method #4 causes a spreading of stickies surface by more than a factor 3 (with hypothesis of conservation of stickies volume). When we run again the model with concentration C measured through INGEDE method #4, we find specific exposure values E_s close to those measured for thin handsheets. That is also apparent from the better fit of the E(%) model with 3DStick data for thick sheets, and better fit with INGEDE data for thin sheets. Future modelling will take into account this spreading effect of protruding fraction of stickies for better prediction of exposure index. We expect the spreading effect to be still significant at low sheet grammage, but of lower magnitude than observed in this study (as the industrial stickies were found to undergo less spreading when pressed on filter compared to these model stickies).

The calculated plateau value for the exposure is $E_s \approx 6.22\times10^{-3}$ m^2/m^2 (with the 3DStick concentration). This computation takes into account the measured distributions of length, width and thickness of the stickies populations, and uses the measured depth and orientation distributions. As we have seen, stickies tend to be uniformly distributed in the depth of the sheet and mostly aligned with the plane of the sheet. In these conditions, the expression of exposure E_s may be approximated to that of the limit case discussed at the beginning (recall eq.(6)), $Z > e/2, E_S = \frac{1}{2}\rho eC$. In the case of the white stickies population, with $\bar{e} = 46$ μm, $C = 361150$ mm²/kg, $\rho = 493$ kg/m³, we find $E_S = \frac{1}{2}\rho eC = 4.1\times10^{-3}$ m²/m². This corresponds to the limit case if all stickies were aligned with the plane of the sheet. This value is only slightly lower than that calculated using the numerical simulation, with distributions of stickies morphology, depth and orientation. This simple expression gives a crude estimation of the minimum value for the surface of stickies exposed at the surface of the sheet (valid for thin stickies or thick sheets).

CONCLUSIONS

In a sheet of paper made from contaminated pulp, only a fraction of the total stickies amount is exposed at the surfaces of the sheet. It is shown that the fraction of stickies which are exposed at the surface of the sheet depends on the stickies morphology, sheet thickness and distribution of stickies within the sheet. A dedicated laser triangulation device has been developed, and offers new information about size and shape of real stickies population. The method also uses NIR spectroscopy to discriminate stickies from other contaminants. Typical stickies objects from recycled pulp were found to have a size of 1000 × 350 × 25 μm³. This provides useful information about the native state of stickies, compared to conventional stickies characterisation methods. Laboratory trials with model stickies show that stickies are uniformly distributed within the thickness of the sheet, and are preferentially aligned with the plane of the sheet. Measurement of stickies exposed at the surface of handsheet show that the number of exposed stickies does not depend on sheet grammage (above a certain sheet thickness). Measured range of exposure is adequately predicted by the model, although differences may arise, probably depending on variable spreading behaviour of stickies particles. Results also suggest that large protruding stickies part may be deformed upon pressing and drying in a sheet of low grammage. This could result in strong adhesion to machine clothes, or to any surface that comes into contact with the paper. Deformation of protruding stickies is less likely to happen in a sheet of higher grammage (or with small stickies, which is equivalent following the stickies exposure concept).

We suggest that stickies related problems in production of recycled paper, are linked to the amount of stickies that are effectively in contact with machine clothes. This would explain why the total stickies concentration in pulp is not sufficient to describe stickies related problems. As a consequence, application in mill of this approach, combining 3D stickies measurements with laser triangulation, and calculation of exposure index, is hoped as an improved mean to anticipate stickies related troubles during paper production. Last step of this work (currently in progress) will therefore focus on correlation between the stickies exposure index with machine runnability.

Finally, we should recall that the geometry of exposed stickies as studied in this work only covers one aspect of stickies deposition problems. Other important phenomena are adhesion and paper strength.

ACKNOWLEDGMENTS

This work was supported by CTP and CTPi members. Participants to the SOLUSTIC project are acknowledged. Thanks are due to A. Balme, J. Bollard, P. De Luca and F. Entressangle (CTP) for experimental work.

REFERENCES

1. M. R. Doshi and J. Dyer, *Paper recycling challenge*, vol. I. Stickies. Doshi and Associates, Inc., Appleton, WI, 1997.
2. A. Blanco, C. Negro, C. Monte, H. Fuente, and J. Tijero, "Overview of two major deposit problems in recycling: slime and stickies. Part II: Stickies problems in recycling," *Progress in paper recycling*, vol. 11, no. 2, pp. 26–37, 2002.
3. Y. Blanc and A. Cochaux, "Problems linked to stickies in a mill recycling packaging materials: industrial experience," in *57th Annual Congress of the ATIP*, Grenoble, France, 2004.
4. F. Julien Saint Amand, "Optimization of Stickies Removal in Screens and Cleaners," in in *Stickies*, vol. 4, Doshi M R. Recent Advances in Paper Recycling—Stickies. Appleton WI: Doshi& Assoc—, 2002, pp. 78–125.
5. B. Carré and G. Galland, "Overview of deinking technology, 8th CTP/PTS Deinking Training Course," CTP, May 2007.
6. B. Perrin and F. Julien Saint Amand, "Deinking rejects analysis in newsprint and copy paper mills," in *Proc. 12th PTS-CTP Deinking Symposium*, Leipzig, Germany, 2006, vol. 31, pp. 1–26.
7. M. A. Hubbe, O. J. Rojas, and R. A. Venditti, "Control of tacky deposits on paper machines-A review," *Nordic Pulp and Paper Research Journal*, vol. 21, no. 2, p. 154, 2006.
8. M. Douek, B. Sithole, and S. Banerjee, "Survey of deposits and contaminants in mills using recycled fiber," *Progress in Paper Recycling*, vol. 13, no. 1, pp. 12–22, 2003.
9. A. Fernandez de Grado and A. Lascar, "Macro, mini, stickies: New challenges," in *PTS-CTP Deinking Symposium 2008*, Leipzig, Germany, 2008.
10. L. Hamann and J. Strauss, "Stickies: definitions, causes and control options," *Wochenblatt fur Papierfabrikation*, vol. 131, no. 11–12, pp. 652–663, 2003.

11. M. Douek, J. Ing, and X. Y. Guo, "An overview of the chemical nature of deposits/stickies in mills using recycled fibre," in *Recycling Symposium*, Chicago, IL, USA, 1997, pp. 313–330.
12. N. N. C. Hsu, J. J. Schroeck, and L. Errigo, "Identification of the origins of stickies in deinked pulp," *Tappi journal*, vol. 80, no. 4, pp. 63–68, 1997.
13. R. Miranda, A. Balea, E. S. de la Blanca, I. Carrillo, and A. Blanco, "Identification of Recalcitrant Stickies and Their Sources in Newsprint Production," *Industrial & Engineering Chemistry Research*, vol. 47, no. 16, pp. 6239–6250, 2008.
14. M. R. Doshi and J. Dyer, "Various approaches to stickies classification," *Progress in Paper Recycling*, vol. 16, no. 4, pp. 44–48, 2007.
15. B. Sitholé and D. Filion, "Assessment of Methods for Measurement of Macrostickies in Recycled Pulps," *Progress in Paper Recycling*, vol. 17, no. 2, pp. 16–25, 2008.
16. J. Andrew, A. Hanuman, and B. Sitholé, "Stickies monitoring at a newsprint and packaging mill," *TAPPSA J.*, vol. 4, pp. 16, 18–20, 22–25, 2011.
17. S. J. Severtson, X. P. Wang, and M. S. Kroll, "Development of environmentally benign pressure-sensitive adhesive systems via modification of substrate properties," *Industrial & Engineering Chemistry Research*, vol. 41, no. 23, pp. 5668–5675, 2002.
18. J. Guo, S. J. Severtson, and L. E. Gwin, "Optimizing the monomer composition of acrylic water-based pressure-sensitive adhesives to minimize their impact on recycling operations," *Industrial & Engineering Chemistry Research*, vol. 46, no. 9, pp. 2753–2759, 2007.
19. J. Guo, S. J. Severtson, L. E. Gwin, and C. J. Houtman, "Effect of amphiphilic additives on the behavior of water-based acrylic pressure-sensitive adhesives during paper recycling," *Industrial & Engineering Chemistry Research*, vol. 47, no. 8, pp. 2612–2617, 2008.
20. J. Flanagan, R. Venditti, H. Jameel, N. Wilson, N. Weaver, and B. Lucas, "Passage of pressure sensitive adhesive particles through a fine slot," *Progress in Paper Recycling*, vol. 11, no. 3, pp. 17–23, 2002.
21. F. Julien Saint Amand, G. Wojciechowski, D. Asendrych, M. Favre-Marinet, R. Rahouadj, and S. Skali-Lami, "Screening: fundamentals studies on the extrusion of stickies through slots," *Revue ATIP*, vol. 58, no. 1, pp. 6–18, 2004.
22. D. Voss, G. Hirsch, H. J. Putz, and S. Schabel, "New Attempt to Complete Recyclability Criteria for Printed Products," in *9th Forum on recycling*, Norfolk, 2010.
23. B. Fabry, T. Delagoutte, A. Guyard, and S. Kumar, "Benchmarking of macrostickies contamination along several deinking lines," in *PTS-CTP Deinking symposium 2010*, Munich, Germany, 2010.
24. M. R. Doshi, W. J. Moore, R. A. Venditti, K. Copeland, H. M. Chang, H. J. Putz, T. Delagoutte, C. J. Houtman, F. Tan, L. Davie, G. Sauve, T. Dahl, and D. Robinson, "Comparison of macrostickies measurement methods," *Progress in Paper Recycling*, vol. 12, no. 3, pp. 34–43, 2003.
25. M. Ricard, G. M. Dorris, S. Gendron, and N. Pagé, "Online macrostickies measurement in an OCC recycling mill," in *PAPTAC Paperweek Canada 2012*, Montreal, Quebec, 2012, pp. 1447–1462.
26. E. Pigorsch, M. Petzold, and G. Gaertner, "New possibilities for paper analysis," *Int. Papwirtsch.*, vol. 1, pp. 44–47, 2012.

27. E. Pigorsch and P. Behnsen, “NIR measuring techniques for the quantification of micro and macro stickies,” *Revue ATIP*, vol. 64, no. 4, pp. 19–22, 2010.
28. R. D. Haynes, “Using the measurement of colloidal microstickies to meet industrial needs for deposit control. part 1: recycle plant,” *Progress in Paper Recycling*, vol. 19, no. 2, pp. 12–29, 2010.
29. B. Carre, J. Brun, and G. Galland, “The incidence of the destabilization of the pulp suspension on the deposition of secondary stickies,” *Pulp & paper Canada*, vol. 99, no. 7, pp. 75–79, 1998.
30. M. Lenes, I. Anerson, and A. Reitan, “Formation of Secondary Stickies in DIP and TMP Suspensions,” in *6th Research Forum on Recycling*, Magog, Quebec, Canada, 2001.
31. L. Hamann, “Latest results of systematic process analysis to reduce stickies in deinking lines,” in *PTS-CTP Deinking Symposium*, Munich, Germany, 2010, vol. 25.
32. P. Huber, T. Delagoutte, and S. Ossard, “The concept of stickies exposure for paper recycling processes,” *Nord. Pulp Pap. Res. J.*, vol. 28, no. 1, pp. 82–93, 2013.
33. M. Ricard, G. M. Dorris, S. Gendron, N. Pagé, D. Fillion, and C. C. Castro, “A new online image analyzer for macrocontaminants in recycled pulps,” *Tappi J.*, vol. 11, no. 2, pp. 19–28, 2012.
34. T. Delagoutte and A. Laurent, “Modified method for quantification of primary stickies in recycled pulp,” *Progress in Paper Recycling*, vol. 10, no. 4, pp. 14–19, 2001.
35. B. Perrin and F. Julien Saint Amand, “Solid reject analyses and stickies balances in a deinking mill and a packaging paper recycling mill,” in *6th KRICT-KTAPPI RTM*, Daejon, Korea, 2005.
36. P. Huber, L. Lyannaz, and B. Carré, “Specks masking by the coating layer in coated paper made from deinked pulp,” *Nordic Pulp & Paper Research Journal*, vol. 28, no. 2, pp. 466–471, 2012.
37. P. Kubelka and F. Munk, “Ein Beitrag zur Optik der Farbanstriche,” *Zeits. f. tech. Physik*, vol. 12, pp. 593–601, 1931.
38. P. Kubelka, “New contributions to the optics of intensely light-scattering materials. Part I,” *J. Opt. Soc. Am*, vol. 38, no. 5, pp. 448–457, 1948.

ANNEXE

Derivation of an analytical expression for *E* in some simple cases

Stickies with uniform orientation distribution

Assuming that (i) stickies length L is constant, (ii) stickies width w is constant, (iii) stickies are 2-dimensional objects (thickness e=0), (iv) stickies orientation distribution is uniform, $g(\theta) = 1$ (v) stickies depth distribution is uniform $h(z) = 1$.

If formation conditions lead to a random orientation for stickies, their orientation distribution is symmetrical around the sheet plane, and it is sufficient to evaluate the stickies exposure index on the 1st quadrant ($0<\theta<\pi/2$).

Then the expression of E (eq.(1) simplifies to:

$$E = \frac{2}{\pi L Z} \int_0^Z \left(\int_\alpha^{\pi/2} L_B d\theta + \int_\beta^{\pi/2} L_T d\theta \right) dz$$

where $\alpha = \sin^{-1}\left(\frac{2z}{L}\right)$ and $\beta = \sin^{-1}\left(\frac{2(Z-z)}{L}\right)$

We set $H_B = \int_0^Z \left(\int_\alpha^{\pi/2} L_B d\theta \right) dz$ and $H_T = \int_0^Z \left(\int_\beta^{\pi/2} L_T d\theta \right) dz$.

For symmetry reasons, $H_B = H_T$, so that $E = \frac{4H_B}{\pi L Z}$.

In order to calculate the expression of H_B, we need to distinguish two cases. If stickies are large compared to sheet thickness they will protrude from the sheet whatever their depth (this concerns stickies which length is higher than twice the sheet thickness). However if they are small they will only protrude when they are close to the surface. Thus, we use the dimensionless stickies length, relative to sheet thickness: $\lambda = L/Z$.

For large stickies with $\lambda > 2$, the expression of L_B can be integrated over the whole sheet thickness (for z going from 0 to Z):

$$H_B = \int_0^Z \left(\int_\alpha^{\pi/2} L_B d\theta \right) dz = \int_0^Z \left(\int_\alpha^{\pi/2} \left(\frac{L}{2} - \frac{z}{\sin(\theta)} \right) d\theta \right) dz = \int_0^Z \left(\frac{L}{2}\left(\frac{\pi}{2} - \alpha \right) - z \int_\alpha^{\pi/2} \frac{d\theta}{\sin(\theta)} \right) dz$$

(in the following, "log" stands for natural logarithm)

With $\int \frac{d\theta}{\sin(\theta)} = \frac{1}{2}(\log(\cos(\theta) - 1) - \log(\cos(\theta) + 1))$, and $\cos(\sin^{-1}(x)) = \sqrt{1-x^2}$ we have

$$H_B = \int_0^Z \frac{1}{4} \left(\pi L - 2L \sin^{-1}\left(\frac{2z}{L}\right) - 2z \log\left(1 + \sqrt{1 - \frac{4z^2}{L^2}}\right) + 2z \log\left(1 - \sqrt{1 - \frac{4z^2}{L^2}}\right)\right) dz = \int_0^Z A(z) dz$$

With

$$\int A(z) dz = \frac{1}{8L}\left(-2z^2 L \log\left(\frac{L + \sqrt{L^2 - 4z^2}}{L}\right) + 2z^2 L \log\left(\frac{L - \sqrt{L^2 - 4z^2}}{L}\right) - L^2\sqrt{L^2 - 4z^2} \right.$$
$$\left. - 4zL^2 \sin^{-1}\left(\frac{2z}{L}\right) + 2\pi z L^2 \right)$$

We then have:

$$H_B = \frac{1}{8}\left(-2Z^2 \log\left(\frac{L+\sqrt{L^2-4Z^2}}{L}\right) + 2Z^2 \log\left(\frac{L-\sqrt{L^2-4Z^2}}{L}\right) - 4LZ\sin^{-1}\left(\frac{2Z}{L}\right) - L\sqrt{L^2-4Z^2} + 2\pi LZ + L^2 \right)$$

Recalling that $E = \dfrac{4H_B}{\pi LZ}$, and using the dimensionless stickies length $\lambda = L/Z$, the stickies exposure E (for $\lambda>2$) can be expressed as:

$$E = \frac{1}{2\pi\lambda}\left(-2\log\left(\frac{\lambda+\sqrt{\lambda^2-4}}{\lambda}\right) + 2\log\left(\frac{\lambda-\sqrt{\lambda^2-4}}{\lambda}\right) - \lambda\sqrt{\lambda^2-4} + \lambda^2 - 4\lambda\sin^{-1}\left(\frac{2}{\lambda}\right) + 2\pi\lambda \right)$$

For small stickies with λ <2, the expression of L_B has to be integrated only over a thickness corresponding to half of the stickies length (for z going from 0 to $L/2$):

$$H_B = \int_0^{L/2}\left(\int_\alpha^{\pi/2} L_B d\theta\right)dz = \int_0^{L/2} A(z)dz$$

This simplifies to: $H_B = \dfrac{L^2}{8}$

With $E = \dfrac{4H_B}{\pi LZ}$, we have: $E = \dfrac{\lambda}{2\pi}$

Stickies parallel to the plane of the sheet

Assuming that (i) stickies length L is constant, (ii) stickies width w is constant, (iii) stickies thickness e is constant, (iv) stickies orientation is parallel to the sheet plane i.e. $g(0)=1$, $g(\theta \neq 0) = 0$, (v) stickies depth distribution is uniform $h(z) = 1$.

Then the expression of E (eq.(1) simplifies to:

$$E = \frac{1}{LZ}\int_0^Z (L_B + L_T)dz$$

In order to integrate this expression, we have to distinguish 3 cases:

If $e < Z$:

$$E = \frac{1}{LZ}\left(\int_0^{e/2} Ldz + \int_{e/2}^{Z-e/2} 0dz + \int_{Z-e/2}^{Z} Ldz\right) = \frac{1}{LZ}\left(L\frac{e}{2} + 0 + L\frac{e}{2}\right) = \frac{e}{Z}$$

If $Z < e < 2Z$:

$$E = \frac{1}{LZ}\left(\int_0^{Z-e/2} Ldz + \int_{Z-e/2}^{e/2} 2Ldz + \int_{e/2}^{Z} Ldz\right) = \frac{1}{LZ}\left(L\left(Z - \frac{e}{2}\right) + 2L(e-Z) + L\left(Z - \frac{e}{2}\right)\right) = \frac{e}{Z}$$

If $e > 2Z$:

$$E = \frac{1}{LZ}\int_0^{Z} 2Ldz = \frac{1}{LZ} 2LZ = 2$$

This reduces to 2 cases

$$\begin{cases} e < 2Z, E = e/Z \\ e > 2Z, E = 2 \end{cases}$$

with $E_S = \frac{1}{2}ECG$ et $G = \rho Z$, we finally have

$$\begin{cases} Z < e/2, E_S = \rho ZC \\ Z > e/2, E_S = \frac{1}{2}\rho eC \end{cases}$$

Transcription of Discussion

A PROPOSED LINK BETWEEN MACHINE RUNNABILITY AND STICKIES DISTRIBUTION WITHIN THE SHEET

Huber P., Delagoutte T., Ossard S., Soysouvanh D., Borel P.

Centre Technique du Papier, CS 90251, 38044 Grenoble, France

Roger Gaudreault Cascades

This is an interesting advance in the area of 3D morphology. So how do you know that the stickies are sticky or, in other words, are going to adhere to the process substrate?

Patrick Huber

Perhaps I did not mention that in the presentation. We have used local NIR (Near Infra Red) spectroscopy to characterise the chemical nature of the contaminants and, during the development of the sensor for each contaminant, we also used the binocular microscope along with a needle to see if it was tacky or not. Then we compared the spectra, and there are some characteristics in the spectra which very nicely correlate with the tacky characteristics.

Roger Gaudreault

Thank you. How much time does it take to perform your (CTP) method compared to the INGEDE (International Association of the Deinking Industry) method?

Discussion

Patrick Huber

Currently, it takes less than an hour to do an analysis but it is the objective for our ongoing work to automate it. Hopefully, we would like to propose, in the near future, a first automated characterisation of the contaminants when they are on the filter paper, and possibly later on, full on-line measurement using this sensor.

Gil Garnier Monash University.

How critical is the fraction of stickies hidden in paper on the runnability?

Patrick Huber

Well we made the hypothesis that they should not cause any problem because they are not likely to be picked up by the machine equipment. Of course this is only a part of the story and you are right, they could create a weak point in the structure and maybe, not only due to adhesion and picking up, they could create stress concentration and potentially cause breaks.

Alessandra Gerli Nalco

You make your handsheets in a handsheet mould. However, the dewatering from a handsheet mould is very different from that on a machine, whether the former is a Fourdrinier, hybrid or gap former, and so the exposure to stickies would be different. So, how can you draw conclusions from this?

My second question is a little bit more tricky. If you want to find a link with machine runnability would it not be better to have a method to measure the stickies in real time, in the process? This is because you want to prevent any runnability issue on the machine and have a predictive method rather than, at a later stage being able to make measurements.

Patrick Huber

Concerning your first question about manufacturing the handsheet, we have not used a standard handsheet mould, we have used the retention handsheet former, that we have at CTP, which is a bit different. Let's say that it creates forming conditions that are a bit closer to paper machine forming, at least in terms of retention. The stock is much more concentrated and you have much faster dewatering: instead of 5 litres, you only drain 0.5 litres in a fraction of a second. It is an open question how well this corresponds to machine forming.

Second question: we are sampling stickies from the pulp, before the paper machine.

Gil Garnier Monash University

Basically, depending on the raw material and process, you start with a certain sticky mass fraction. So my question is, what is the best strategy? Is it better to coagulate your stickies into few big chunks and then try to keep them at the surface or to hide them inside paper? What is the best strategy to improve runnability?

Patrick Huber

In this work, we have tackled only the problem of macro-stickies, which are macroscopic objects and so are less likely to be flocculated by chemicals. Your question seems to relate more to micro-stickies and possible agglomeration of colloidal material which will then lead to secondary stickies, requiring a different strategy. If you have small objects, we would recommend dispersing them rather than causing them to agglomerate at any stage of the process. For the larger stickies, you should try to screen them out as best as you can. We think that an on-line development of this method would give you knowledge to at least react a little bit quicker and if you see a "sticky storm" coming in, you may decide that it is better to throw away this pulp for some time before you go back to normal operations. That would be a new opportunity, as, presently, we are not even able to monitor stickies.

Tetsu Uesaka Mid Sweden University

I am intrigued by the title of your talk and the proposed link between machine runnability and stickies. Of course I am aware that it is known that stickies create breaks, but, based on your measurements, how would you create a link between machine runnability and your measurements? It is extremely difficult to establish such a relationship, simply because breaks are rare phenomena; it is an extreme value problem.

Patrick Huber

Up to now, we have not had the opportunity to do that on a paper machine, and we have only done lab work. There are several plans for future work, some of which are new analyses of machine data by measuring the morphology of the stickies with a high frequency. So what we could imagine is that, for one given production and one given pulp grade, you detect a variation of the stickies morphology coming: does that translate into a higher frequency of breaks or increased deposits? Also, does a specified grammage combined with a given stickies morphology produce an impact on deposits and breaks? But this work remains to be done.