A novel method for the determination of linting propensity of paper

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ABSTRACT: A novel method was developed for the determination of linting propensity of paper based on printing with an IGT printability tester and image analysis of the printed strips. On average, the total fraction of the surface removed as lint during printing is 0.01%-0.1%. This value is lower than those reported in most laboratory printing tests, and more representative of commercial offset printing applications. Newsprint paper produced on a roll/blade former machine was evaluated for linting propensity using the novel method and also printed on a commercial coldset offset press. Laboratory and commercial printing results matched well, showing that linting was higher for the bottom side of paper than for the top side, and that linting could be reduced on both sides by application of a dry-strength additive. In a second case study, varying wet-end conditions were used on a hybrid former machine to produce four paper reels, with the goal of matching the low linting propensity of the paper produced on a machine with gap former configuration. We found that the retention program, by improving fiber fines retention, substantially reduced the linting propensity of the paper produced on the hybrid former machine. The papers were also printed on a commercial coldset offset press. An excellent correlation was found between the total lint area removed from the bottom side of the paper samples during laboratory printing and lint collected on halftone areas of the first upper printing unit after 45000 copies. Finally, the method was applied to determine the linting propensity of highly filled supercalendered paper produced on a hybrid former machine. In this case, the linting propensity of the bottom side of paper correlated with its ash content.

Application: This paper describes a laboratory method that can be used to evaluate the linting propensity of uncoated mechanical papers.

Increased use of recovered fiber and substitution of fiber for filler have significantly reduced the surface strength of paper, affecting papermaking and printing operations. A resulting problem for printers is linting, defined as the detachment of loosely bonded fibers and fines from the paper surface during offset printing and their accumulation on the printing blanket [1]. The detached material can travel into the inking system, eventually preventing the transfer of ink to the paper. This causes deterioration of the image quality to the point that the printing press needs to be stopped for washing or maintenance. Offset processes are especially prone to linting because they subject the surface of paper to significant stress forces as the tacky ink splits at the exit of the printing nip. Linting issues have become more severe with increasing use of heatset web offset to print uncoated mechanical papers.

Linting has been the subject of intense investigations for more than 40 years because of its economic effect on paper machine and printing press operations [2]. Pulp quality [3-5], paper machine configuration and operational parameters [5,6], and printing press variables [7-10] all influence linting. Much research has also been devoted to identifying reliable laboratory methods to predict the linting behavior of a paper on a printing press. The availability of such a method is critical for anticipating print runnability issues and quickly defining the best papermaking strategy to improve the surface strength of paper. Commonly used lint tests have been reviewed by Mangin [11] and Aspler [12]. Most tests are based on detachment of fibers from the paper surface and analysis of the collected debris. Detachment can be performed, for example, using a weakly adhesive tape [13,14] or in a laboratory-printing nip using a viscous fluid.

The standard IGT printing test (ISO 3783:1980 “Paper and board – Determination of resistance to picking – Accelerating speed method using the IGT tester [electrical model]”) uses a viscous fluid to exert a pulling action force on the surface of paper. The test is performed by placing the inked printing disc under pressure against paper mounted on a circular sector [15,16]. The sector is run against the disc under acceleration from zero to some preset end-velocity. The surface strength of paper (pick resistance) is derived by measuring the distance between the starting point of the print and the position of the print where the first damage occurs. One drawback of the IGT test, as performed following the standard procedure, is that high stresses are applied to the surface of the paper. Therefore, the test serves more as an evaluation of the bonding potential of fiber than the true paper linting tendency [11,14]. Additionally, for mechanical grade papers, such as newsprint, the visual assessment of the picking point on paper using a transparent oil is difficult [15]. To overcome these issues, a test method was developed that uses a printing oil with lower tack and viscosity, as compared with the standard IGT method [17,18]. For the test, lint accumulated on the printing disc is collected and quantified using a fiber analyzer. Appropriate selection of printing oil and speed resulted in lint size distributions similar to those of lint collected on the blanket of an offset press [17,18].

A novel method for determining the linting propensity of mechanical papers was developed in the Nalco Company laboratory. Paper strips were printed using an IGT printability tester and accelerating speed mode. By using red ink instead of oil, the area and number of particles removed from the printed strips can be quantified using image analysis. Printing conditions (e.g., ink viscosity, final printing speed, and printing pressure) can be selected to obtain desired results, such as to remove a limited amount of lint particles from the test strips and still achieve differentiation among samples. On average, the total fraction of the surface that is removed as lint is 0.01%-0.1%. This value is lower than those reported in most laboratory printing tests [19], and more representative of commercial offset printing applications. Nalco has now used the test for more than three years to predict the linting propensity not only of paper grades containing marginal amounts of filler such as newsprint and directory papers, but also grades containing significant amount of filler, such as supercalendered (SC-A and SC-B) papers. Three representative mill case studies are presented in this paper. They cover the practical application of this novel method and its validation through correlation with commercial printing press results.

EXPERIMENTAL

Paper properties

Paper sheets were conditioned in a constant temperature and humidity room at 23°C and a relative humidity of 50% for 24 h before testing.

Caliper

Sheet caliper was measured by using an L&W micrometer (code 050) from Lorentzen & Wettre (Kista, Sweden) at eight random positions on every sheet using a foot pressure of 50±2 kPa. A total of five sheets per sample were analyzed. Caliper and grammage values were used in the calculation of sheet bulk.

Permeability

Sheet permeability was measured by using an L&W Bendtsen tester (code SE 114), equipped with a 10 cm^2 measuring head. Eight measurements per sheet were performed and a total of five sheets per sample were analyzed. Measurements were carried out at a standard pressure of 1.47±0.02 kPa according to ISO 5636-3 “Paper and board-determination of air permeance (medium range) - Part 3: Bendtsen method second edition.”

Bendtsen roughness

Bendtsen roughness was measured by using an L&W Bendtsen tester. Sheet samples were held between the measuring head and a glass plate. Four measurements per sheet side were performed and a total of five sheets per sample were analyzed. Measurements were carried out at a standard pressure of 1.47±0.02 kPa according to ISO 8791-2 “Paper and board – determination of roughness/smoothness (air leak methods) – Part 2: Bendtsen method. ”

Parker Print-Surf roughness

Sheet roughness was measured by using an L&W Parker Print-Surf (PPS) roughness tester (code SE115). Sheet samples were fixed between the measuring head and the base with a clamp pressure of 1 MPa (soft backing). Four measurements per sheet side were performed and a total of five sheets per sample were analyzed.

Beta-formation

Beta-formation was measured by using a beta-formation tester from Ambertec (Espoo, Finland). The instrument determines the deviation from the mean weighted sheet basis weight. Normalized formation values were obtained by dividing the standard deviation of the basis weight (formation) by the square root of the basis weight. Two measurements per sheet were performed, and a total of five sheets per sample were analyzed. Each measurement consisted of 400 measured points. The pulse counting time was 0.4-0.6 s.

Tensile strength

Tensile properties were measured using an electromechanical tensile tester from TestResources Inc. (Shakopee, MN, USA). The span length used was 140 mm. The tensile load was applied at a constant speed of 25 mm/min. Two measurements per sheet (cross direction and machine direction) were performed and a total number of five sheets per sample were analyzed.

Z-filler distribution analysis

The paper sample was sandwiched between two laminator foils and inserted in a hot laminator. After lamination, the sample was split manually into halves. The procedure was repeated until enough splits were made. The basis weight of each split was determined by subtracting the weight of the foil from the weight of foil and paper. The splits were subsequently ashed, and the z-filler distribution profile was depicted by plotting the percent ash content of the individual layer versus the relative basis weight (% basis weight at which splitting occurred).

Fiber fines determination

After being soaked overnight, the paper samples were disintegrated at 1.2% consistency for 45000 revolutions using a standard disintegrator. The stock was diluted with deionized water to 0.5% consistency for fines fractionation, a dispersant solution at 1% was added, and the stock was disintegrated for 1 min. The total fines content was determined following TAPPI T 262 cm-94, “Fine fraction of paper stock by wet screening.” The solid collected from the filtrate was ashed and the fiber fines content determined from the weight difference of the solids before and after ashing. The procedure was repeated three times for each sample and the results averaged.

Coldset offset printing trial

Machine-finished uncoated mechanical papers were printed on a Heidelberg Web-8 printing press (Heidelberger Druckmaschinen AG; Heidelberg, Germany) at a controlled temperature of 22°C and relative humidity of 48%. The target 4/4 color print density was 0.8 for cyan and magenta, 0.85 for yellow, and 1 for black. The printing speed was 4.4 m/s (25000 rph). The in-feed web tension was 260 N. The fountain solution had a pH of 5.3 and conductivity of 1250 µS/cm. An average of 260 L of fountain solution was used for each trial point.

IGT printing

Printing tests for the determination of linting propensity of paper were performed using an IGT AC2 model electrically driven printability tester used in combination with an IGT AE inking unit from IGT Testing Systems (Amsterdam, The Netherlands). We added 8 µm of ink (Huber ink 404.800.002 Nr. 2, medium tack; IGT Testing Systems; Amsterdam; The Netherlands) to the top roller of the inking unit. Following ink distribution, a 32 mm-wide, rubber-coated printing disc was inked for 45 s and inserted after being weighed on the upper printing shaft of the printability tester. A print was made on the test strip in accelerating mode, using a printing force of 400 kN. The end-speed selected was 2 m/s or 4 m/s. The printing disc was re-weighed after printing. The inking unit was cleaned after each print run. Images of the printed samples were obtained by scanning the printed strips in reflected mode at 600 dpi using a flatbed scanner (Epson Expression 10000 XL).

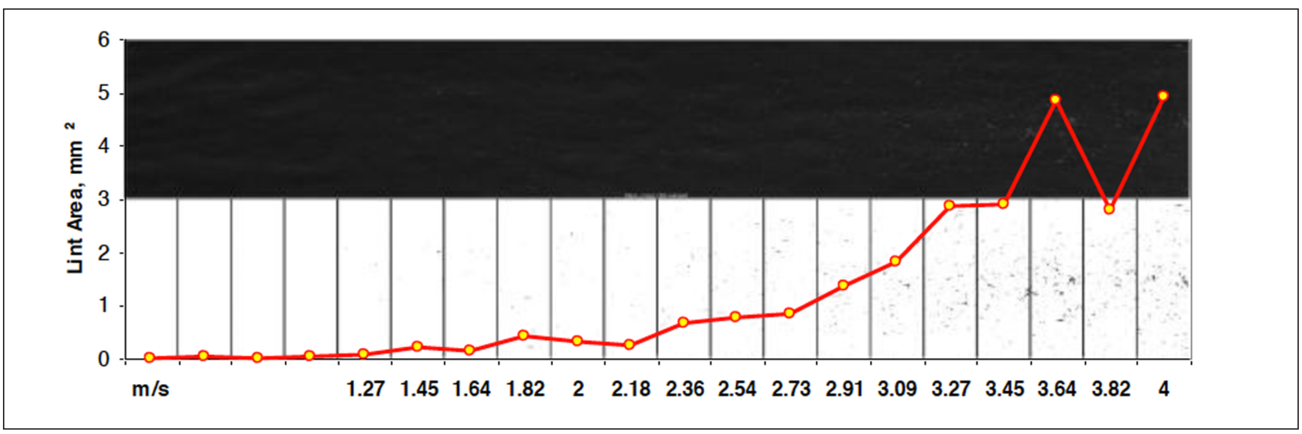
RESULTS AND DISCUSSION

Test method development

The method developed is based on the IGT linting test [20], but it uses a new way of analyzing the linting propensity of the printed strips. Printing is performed in accelerating speed mode using medium viscosity red ink. For comparison, paper samples need to be printed at the same end-speed, because changes of end-speed influence the results [11]. End-speeds of 2 m/s or 4 m/s were suitable to remove a limited amount of lint particles from the test strips for mechanical grade papers and still achieve differentiation among samples. Next, gray images of the printed strips are acquired using a flatbed scanner. Image processing is carried out using the ImageJ program (National Institutes of Health; Bethesda, MD, USA) [21]. ImageJ is freely available, Java-based software that has sets of ready-made tools for image manipulation and plugins to extend its core functionality. A macro was developed for automatic determination of the number of lint particles and their area. The macro includes the following steps: alignment of the images, selection of the printed area, exclusion of a fixed area on the edges, and automatic thresholding. A maximum entropy threshold algorithm available as plugin in ImageJ was found suitable to detect the small defects corresponding to the particles removed as lint on the original images. Additional steps include inversion of the binary images and their segmentation in 20 parts, each corresponding to a different, increasing printing speed. **Figure 1** shows a representative montage obtained for a printed strip. Quantification of the number and area of the lint particles in each of the 20 adjacent segments allows distinguishing between unbound, loosely, or more strongly bound particles. Thus, the true linting propensity of a paper can be derived. For mechanical grade papers, no correlations were found between linting propensity results obtained using the described method and surface properties of paper such as PPS or Bendtsen roughness results. Such correlations would indicate that the small defects are the result of nonhomogeneous ink coverage on the paper at micro or macro levels rather than due to fines and fiber removal.

Case study I: newsprint paper

A trial with a dry-strength agent was run on a newsprint machine with the goal of improving the surface strength of



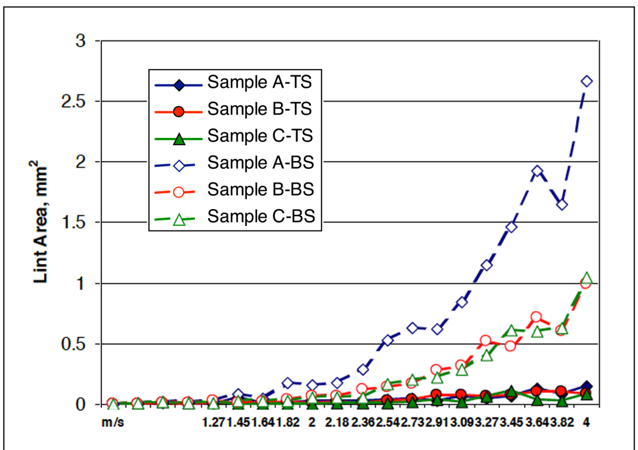
1. Example of montage obtained with ImageJ, including the original scanned image of the printed strip and the processed image. Quantification of lint particles removed from the printed strip was carried out in 20 adjacent segments, each corresponding to a different and increasing printing speed.

	Grade	Paper Machine	Dry-Strength Additive, kg/t	Basis Weight, g/m^2	Ash, %	Bulk, cc/g	N. Beta-Formation, $\sqrt{g/m}$	Ash, %		PPS Roughness, µm		Bendtsen Roughness, mL/min		Tensile Index, Nm/g		Fiber Fines, %
								Top	Bottom	Top	Bottom	Top	Bottom	MD	CD	
Sample A	Newsprint	Gap	0	41.4	8.9	1.48	0.407	8.8	10.1	3.90	3.44	138	136	58.7	15.1	–
Sample B	Newsprint	Gap	1	41.8	8.9	1.50	0.415	7.7	10.2	3.94	3.57	144	149	62.0	14.7	–
Sample C	Newsprint	Gap	2	41.2	8.9	1.50	0.420	8.6	9.5	4.06	3.56	143	141	65.0	14.4	–
Sample D	Machine-finished	Gap	–	51.5	7.2	1.62	0.541	8.8	7.4	3.81	3.93	116	137	55.8	16.8	24.1
Sample E	Machine-finished	Hybrid	–	51.8	6.0	1.62	0.426	7.0	3.6	4.28	3.49	152	111	45.4	17.5	21.2
Sample F	Machine-finished	Hybrid	–	51.8	8.9	1.58	0.450	10.3	6.3	4.10	3.44	136	99	43.9	16.9	20.9
Sample G	Machine-finished	Hybrid	–	52.3	6.4	1.60	0.450	6.4	5.6	4.17	3.51	141	110	46.8	17.3	22.2
Sample H	Machine-finished	Hybrid	–	52.4	6.2	1.61	0.431	7.4	3.5	4.03	3.48	137	104	46.7	17.5	20.1
Sample I	Supercalendered	Hybrid	–	55.2	32.1	0.89	0.407	43.3	25.2	1.25	1.22	–	–	43.4	14.7	–
Sample J	Supercalendered	Hybrid	–	46.8	22.9	0.99	0.425	42.7	17.7	1.37	1.34	–	–	53.6	16.7	–
Sample K	Supercalendered	Hybrid	–	56.7	31.5	0.89	0.460	28.5	29.9	1.24	1.26	–	–	45.3	14.8	–

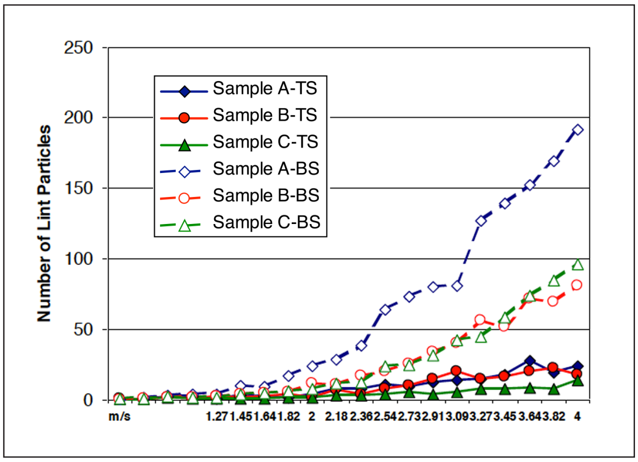
I. Properties of paper samples evaluated for linting propensity.

paper. The mill had been having recurrent linting issues and eucalyptus vessel picking problems for their paper during printing press operations. The problems were most severe with heatset offset printing, but problems also occurred during coldset printing, which was used for most of the production. The mill's paper machine is a high-speed roll/blade gap former with a three-nip press and a shoe press in the third nip. The furnish composition was 50% thermomechanical pulp and 50% deinked pulp.

Three reels of paper (a reference reel and two reels produced with the dry-strength agent at different dosages) were collected and characterized for sheet properties and linting propensity using the new method. The sheet property data and the amount of filler on the two sides of paper derived from z-filler distribution analysis are illustrated in **Table I**. **Figure 2** shows the area of particles removed as lint from the top and bottom sides, as a function of the printing speed.



2. Lint area as a function of printing speed removed from the top (TS) and bottom (BS) sides of sample A (reference), sample B (1 kg/ton of dry-strength additive), and sample C (2 kg/ton of dry-strength additive).



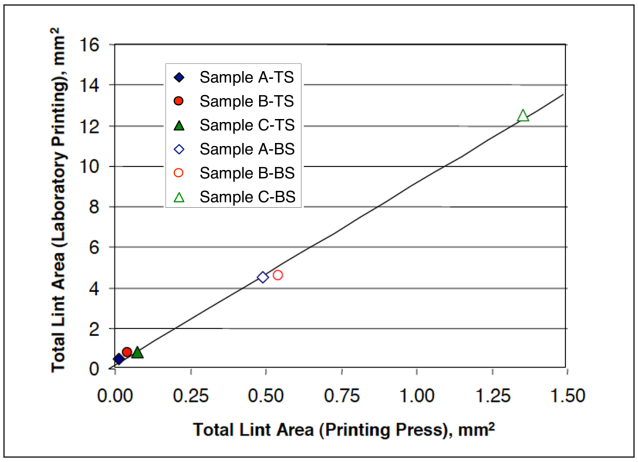
3. Number of lint particles as a function of printing speed removed from the top (TS) and bottom (BS) sides of sample A (reference), sample B (1 kg/ton of dry-strength additive), and sample C (2 kg/ton of dry-strength additive).

The number of particles versus printing speed is plotted in **Figure 3**. The data show that the bottom side of paper has significantly higher linting propensity than the top side, consistently with what the mill was reporting for commercial printing press operations. On average, the total fraction of the area that was removed as lint was about 0.01% on the paper top side and 0.11% on the paper bottom side. Adding dry-strength agent significantly reduced the linting propensity on the top and bottom sides. For all three samples, slightly higher filler content was found for the paper bottom side when compared to the paper top side (Table I). A higher filler amount, generally speaking, reduces strength and facilitates fiber and fines removal. This might suggest that the bottom side surface is weaker because of its higher filler content. However, additional investigations performed on paper produced on the same machine found that the bottom surface gave more linting than the top side, even when its ash content was lower.

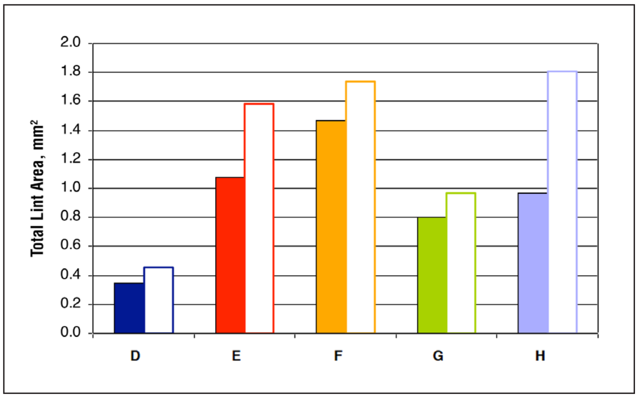
The mill sent the three paper reels to a printing house for qualitative assessment of linting. The paper was printed in

	Area of White Spots on Magenta, mm²		Number of White Spots on Magenta	
	Top Side	Bottom Side	Top Side	Bottom Side
Sample A	0.078	1.356	7.00	62.50
Sample B	0.046	0.544	4.75	32.00
Sample C	0.014	0.493	3.00	32.75
	Area of White Spots on Black, mm²		Number of White Spots on Black	
	Top Side	Bottom Side	Top Side	Bottom Side
Sample A	0.105	1.203	25.25	97.75
Sample B	0.168	0.720	27.25	66.25
Sample C	0.068	0.240	18.75	34.50

II. Total area and number of white spots quantified by image analysis on magenta (total area analyzed = 51.3 cm²) and black (total area analyzed = 54.9 cm²) solid prints of the test target printed on a commercial coldset offset press.



4. Correlation between total area removed as lint from the test strips during laboratory printing and total area of white spot defects on magenta solid color of the printing press test target.



5. Total lint area removed during laboratory printing from the top (solid color bar) and bottom (empty color bars) sides of the machine-finished paper samples produced on the gap former (sample D) and hybrid former (samples E, F, G, and H) machines. The paper samples were printed in accelerating speed mode using 2 m/s as the end velocity.

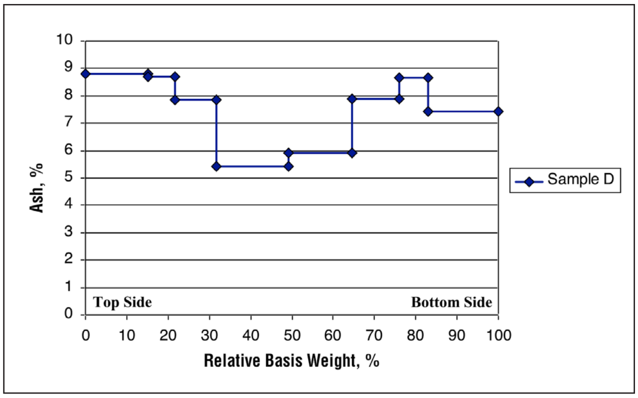
coldset offset using a CMYK printing sequence. The printed samples showed a significant amount of white spots on solid black, cyan, and magenta prints. The spots were likely produced by lint particles on the plate or blanket that prevent printing. Solid black and magenta prints had uniform color, whereas the solid cyan print mostly was not uniform. As a result, solid black and magenta prints were chosen for image analysis quantification of the total number of white spots and their area. The results matched the laboratory printing results; in particular, addition of the dry-strength additive significantly reduced the number of white spots on black and magenta solid prints (**Table II**). More white spots were found on the paper bottom side than on the top side. The correlation between the total area removed as lint from the test strips during laboratory printing and the total area of white spot defects on magenta solid color of the printing press test target was excellent ($r^2 = 0.998$) (**Figure 4**).

Case study II: machine-finished uncoated mechanical paper

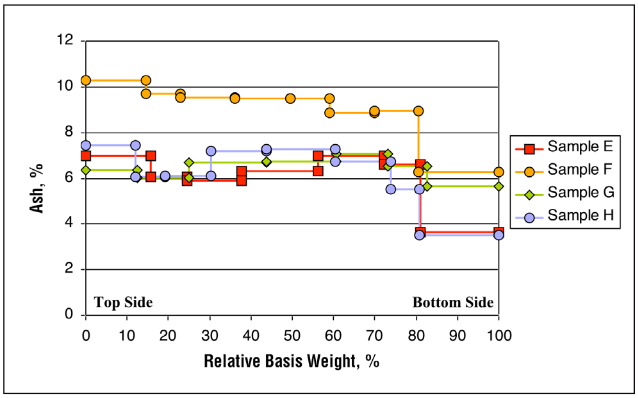
A wet-end chemistry trial was run on a hybrid former machine producing machine-finished uncoated mechanical paper. The goal was to reduce the linting propensity of the paper produced, matching the good quality of paper of the same grade produced on a paper machine with a gap former configuration. Both machines were provided with a three-nip press. The furnish composition for both machines was a mixture of kraft, thermomechanical, and groundwood pulps.

One paper reel produced on the gap former machine (sample D) and four paper reels produced on the hybrid former machine using different wet-end conditions (samples E, F, G, and H) were characterized for sheet properties and linting propensity. Table I presents the sheet property data. Paper samples E and F were produced at standard first pass retention. The addition of fresh filler on the machine was increased to produce sample F. At the same time, the retention program addition levels were increased to maintain retention. Samples G and H were produced at higher retention. The filler (ground calcium carbonate) addition point was at the fan pump for all the samples. For sample H, the filler addition point was moved from the fan pump to after the blend chest. Adding filler back into the system (sample H) allowed reduction of the retention program dosage while maintaining retention.

The five samples were analyzed for linting propensity using the novel method we developed. **Figure 5** shows the total lint area values (sum of lint areas on the 20 adjacent segments on the printed strips) for top and bottom sides of the five samples. Sample D, the reference paper, showed the lowest linting value. Sample G was the best among the samples produced on the hybrid former machine. For the gap former machine, linting propensity on the two sides of paper (sample D) was similar. For the hybrid former machine, the bottom side of the paper samples (samples E, F, G, and H) had higher



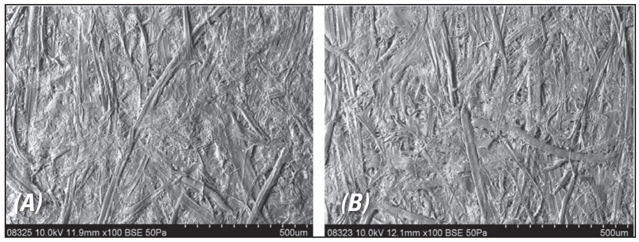
6. Z-filler distribution of sample D, produced on the gap former machine.



7. Z-filler distribution of samples E, F, G, and H, produced on the hybrid former machine.

linting propensity than the top side.

We determined the z-filler distribution for the five paper samples to identify the structural features of the sheet that might induce differences in linting behavior between top and bottom sides of paper. **Figure 6** shows the z-filler distribution of sample D produced on the gap former machine. **Figure 7** shows the z-filler distribution of samples E, F, G, and H produced on the hybrid former. Among the samples produced on the hybrid former machine, sample G had the lowest filler two-sidedness. Lower filler two-sidedness likely resulted from improved first pass retention. The bottom sides of samples E, F, G, and H had higher linting propensity, despite having lower ash content. There are two possible explanations for this finding. If the distribution of fiber fines follows that of filler, then higher amount of fiber fines on the top side of the samples might counteract the weakening effect of higher amount of filler and lead to an overall strengthening effect on the top side. Additionally, the third press nip might play an important role in reducing the linting tendency of the top side of paper. Paper samples E, F, G, and H were produced on the same day, with no variation of press loads. The higher roughness of their top side compared with the bottom side (Table I) is indicative of a higher imprint by the felt in the third nip associated with improved top surface consolidation. Images of the surfaces of all five sheets were taken with a scanning

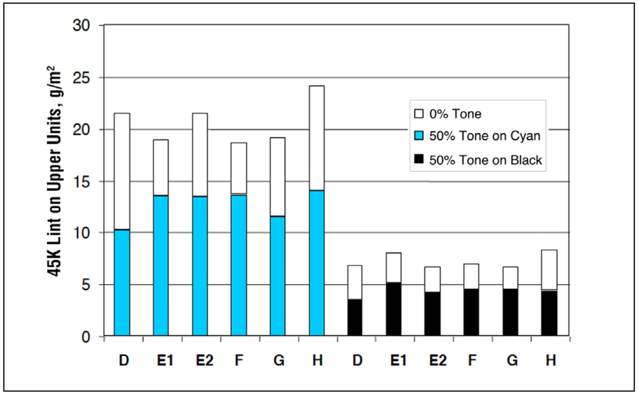


8. Scanning electron microscope images of the top (A) and bottom (B) sides of sample G. The top, lower linting surface contains more fines with less open cavities between fibers.

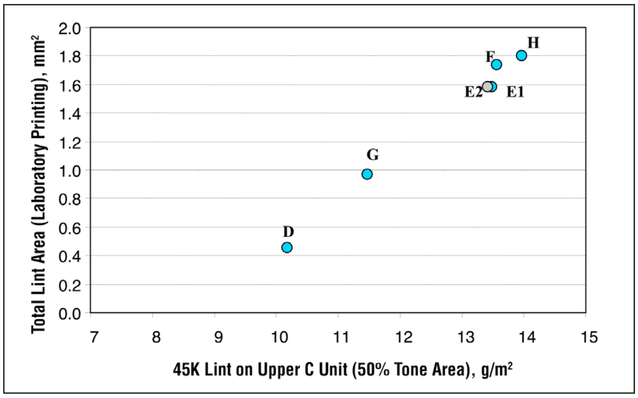
electron microscope. The images clearly showed that both top and bottom surfaces of the sheets are well consolidated, but the top side had more fines with less open cavities between fibers. **Figure 8** shows images of the top and bottom surface of sample G.

Previous studies showed that high concentrations of fiber fines at the surface, as long as they are well consolidated, may reduce linting [22,23]. An increase of surface fines coupled with strong compaction of the surface during pressing would produce a low linting surface [9]. This prompted us to examine the fiber fines content of the five samples. Table I shows the results. A good correlation ($r^2 = 0.969$) was found between the linting propensity of the bottom side, determined with the novel method, and the fiber fines content of the five samples. Sample D, produced on the gap former, had the lowest linting propensity among all the samples, and the highest fiber fines content. Among the samples produced on the hybrid former machine, sample G, with the lowest linting propensity, also had the highest amount of fiber fines. Thus, the results indicate that the retention program, by improving fiber fines retention, substantially reduced the linting propensity of the paper produced on the hybrid former machine. Samples G and H were produced at high first pass retention. For sample H, which was produced with filler added back into the system, mechanical entrapment of the filler partly contributed to higher first pass retention values (e.g., reduced dosages of retention chemicals were needed to maintain retention). Clearly, these conditions caused reduced chemical retention of fiber fines, with increasing linting as a result.

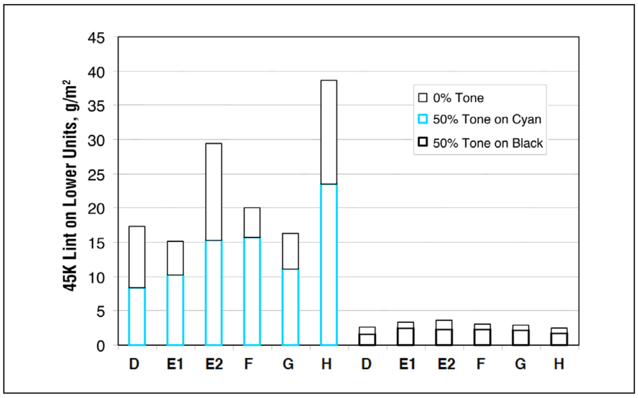
The five reels of papers also were printed on a commercial coldset offset press using the CMYK sequence. The bottom side of the paper samples (Table I) was printed toward the top press blanket and the top side toward the bottom press blanket. The lint that accumulated on the first and fourth printing units after 15000 and 45000 copies was collected using tape pulls from the halftone and unprinted areas. **Figures 9** and **10** show lint collected after 45000 copies for the top and bottom side blankets, respectively. A higher amount of lint was collected on the cyan units (upper and lower) than on the black units (upper and lower) in halftone and unprinted areas after 15000 or 45000 copy printing. Sample E was printed twice (trial runs E1 and E2) (Figs. 9 and 10), before and after changing of the printing plates for damage. The printing plates also were replaced after running sample G.



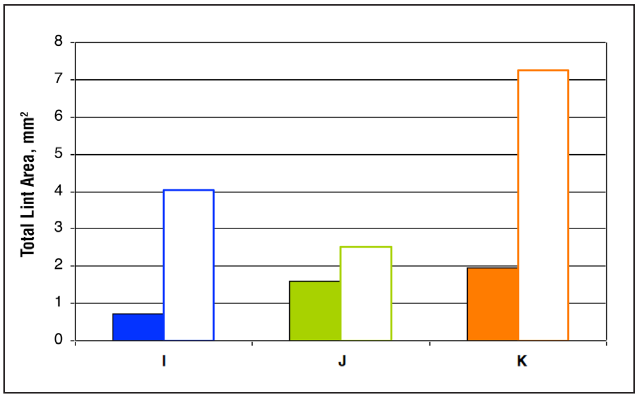
9. Amount of lint collected after 45000 copies on the upper cyan and black printing units in the unprinted and halftone areas. The bottom side of the paper samples was printed toward the upper printing units.



11. Correlation between total area removed as lint from the bottom side of the paper samples during laboratory printing and lint collected on the upper first printing unit (cyan) used to print this side of paper.



10. Amount of lint collected after 45000 copies on the lower cyan and black printing units in the unprinted and halftone areas. The top side of the paper samples was printed toward the lower printing units.



12. Total lint area removed during laboratory printing from the top (solid color bar) and bottom (empty color bars) sides of the supercalendered paper samples. The paper samples were printed in accelerating speed mode using 2 m/s as the end velocity.

The reproducibility of the amount of lint collected after 45000 copies was excellent for the halftone areas of the cyan upper unit (coefficient of variation = 0.4%). The repeatability was less positive for the lint collected on the halftone areas of the black upper unit (coefficient of variation = 15.2%). The repeatability was poor for linting collected in unprinted areas of the cyan upper unit (coefficient of variation = 28.0%). For printing toward the bottom press blankets, the repeatability was very poor overall in both halftone and unprinted areas. Samples D, E1, and G linted more on the bottom side than on the top side, as was discovered in the laboratory results. For samples E2, F, and H, linting on the top side was higher. The side of paper that gave more linting changed when printing was repeated (trial runs E1 and E2); therefore, the structural characteristics of the paper and printing press operation variables played a major role in determining which side of paper is linting more.

We found an excellent correlation ($r^2 = 0.991$) between the total lint area removed from the bottom side of the paper samples during laboratory printing and the lint collected on the halftone areas of the upper cyan unit after 45000 copies (**Fig. 11**). This is the printing unit for which the lint amount estimation was very good. Sample F, produced with higher ash content, had relatively less linting after 15000 copies than after 45000. Thus, the correlation between laboratory results and lint collected on halftone areas of the first unit after 15000 copies was less ($r^2 = 0.62$; $r^2 = 0.87$, excluding sample F). Poor correlations were found between laboratory results and lint collected on black units and in unprinted areas. On the other hand, the coefficient of variation for the repeatability of the lint collected in these areas was very high.

Overall, laboratory and commercial printing data showed that the reference sample D produced on the gap former machine had the lowest linting propensity. Additionally, higher first pass retention conditions used to produce sample G were the most promising to reduce the linting propensity of the paper produced on the hybrid former machine.

Case study III: supercalendered paper

The test method we developed can also be applied to mechanical papers containing high amounts of filler, such as supercalendered grades. A mill producing SC-A paper was concerned about linting and dusting issues for the paper produced on one of their machines and asked to investigate papermaking factors that could be addressed to reduce it. Three paper samples produced on this machine were analyzed for sheet properties, z-filler distribution profile, and linting propensity. Table I shows the sheet properties data for the three samples and the amount of filler on the two sides of paper derived from z-filler distribution analysis.

Testing confirmed that the bottom side of the paper samples had higher linting propensity than the top side (**Fig. 12**), consistent with what the mill was reporting for printing press operations. The linting propensity of the bottom side correlated with the amount of filler on the bottom surface; the higher the filler, the higher the linting propensity ($r^2 = 0.889$). The sample that had the highest linting propensity (sample K) was the one with the lower filler two-sidedness and poor beta-formation. Thus, improved control of the z-filler distribution profile through adjustment of mechanical, operational, and chemical parameters was proposed to minimize linting and dusting propensity issues.

CONCLUSIONS

We have developed a novel method to determine the linting propensity of mechanical papers. Paper strips were printed with a medium viscosity red ink in accelerating speed mode, using an IGT printability tester. Quantification of the number and area of the lint particles in 20 adjacent segments on the printed strips allowed distinguishing between unbound, loosely, or more strongly bound particles. Thus, the true linting propensity of a paper can be derived. The method was validated through correlations with commercial printing results and used successfully in the last years to guide papermakers on the best approach to address linting issues.

In the first of our three case studies, the method was used to assess the effect of a dry-strength agent on the linting propensity of newsprint paper. The results showed that adding a dry-strength agent significantly reduced the linting propensity on both sides of the paper. The same paper reels were printed on a commercial coldset offset press. The total area removed as lint from the test strips during laboratory printing correlated with the total area of white spot defects on magenta solid color of the printing press test target.

In the second case study, four reels of machine-finished uncoated mechanical paper were produced on a hybrid former machine using different machine wet-end conditions. The goal was to reduce the linting propensity of the paper produced, matching the good quality of paper of the same grade produced on a paper machine with gap former configuration. The laboratory linting results and quantification of the fiber fines content of the sheets indicated that the retention program, by improving fiber fines retention, substantially reduced the linting propensity of paper. The papers also were printed on a commercial coldset offset press. The correlation between the total lint area removed from the bottom side of the paper samples during laboratory printing and the lint collected on the halftone areas of the upper first printing unit was excellent.

Finally, in a third case study, the method was used to determine the linting propensity of highly filled SC-A paper. The linting propensity of the bottom paper surface correlated with its ash content. Because mechanical, operational, and chemi-

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Linting during printing press operations remains a major source of complaints, especially with increasing use of heatset web offset to print uncoated mechanical papers. We worked on the development of a laboratory test method to predict the linting propensity of paper to guide papermakers on the best approach to address linting problems.

This work is a continuation of our previous work, examining the surface strength of uncoated woodfree papers using the traditional picking resistance laboratory printing method. We were looking for a method that would use image analysis rather than visual assessment to quantify the linting propensity of mechanical papers. The use of a red ink rather than a transparent oil has been fundamental in being able to quantify the small defects on the printed strips corresponding to particles removed as lint. The most difficult task was the development of an image analysis macro program for automatic and fast assessment of the linting propensity of paper. The correlations we found with commercial printing results support the validity of the method.

One surprising finding was that the retention program, by improving fiber fines retention, substantially reduced the linting propensity of paper. Thus, its proper selection and fine-tuning may offer a cost-efficient solution for papermakers interested in addressing linting.

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Our next step is to work on the development of a method that could be used to predict dusting of reprographic papers. Dusting issues are an increased concern for papermakers as a result of current efforts to increase the ash content of paper.

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cal parameters influence the z-filler distribution profile, their control to address linting is critical in the case of highly filled grades. **TJ**

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