Dynamic Optical Measurement of Lint Accumulation during Offset Printing

Rosiana Lestiani,[a] Warren Batchelor,[a,*] and Paul Banham [b]

Linting occurs when small particles are removed from the paper surface by the splitting of the tacky ink film. Excessive linting reduces printing quality and can affect the pressroom efficiency. An improved method, using video camera technology, has been utilized to measure the dynamics of linting during the printing process. This technology makes it feasible to estimate the removal of lint particles from the paper and from the blanket surfaces. This article presents the latest development of the lint camera system and its applications under different press conditions, including ink color. The lint measurements obtained by the camera system were compared with the established measurement methods (blanket tape pull and blanket wash). The main result from this study indicates some similarities in the lint area distribution measured by the camera system and the blanket tape pull. The differences in the lint area distribution from the filtered sample at small particle sizes is likely due to disaggregation of the agglomerated lint particles during the washing and filtering, and as a result, of more small particles being measured from the tape pulls.

Keywords: Lint measurement; Linting dynamics; CCD camera; Image analysis; Offset printing

*Contact information: a: Australian Pulp and Paper Institute, Department of Chemical Engineering, Monash University, PO Box 36, Clayton, Victoria 3800, Australia; b: Norske Skog Technical Support and Development, Boyer, Tasmania 7140, Australia; *Corresponding author: warren.batchelor@monash.edu*

INTRODUCTION

The linting phenomenon occurs when particles come loose from the surface of uncoated paper during offset printing. The accumulation of lint on the printing blanket will eventually cause deterioration in image quality, as shown in Fig. 1, up to the point where the press has to be stopped for cleaning. Linting has, therefore, a major effect on pressroom efficiency.

Fig. 1. Lint accumulation on the blanket is shown on the left hand side, and the right image shows the deterioration in the quality of the printed image as a result of lint accumulation.

There are many challenges to measure linting from a paper sample. First, most of the lint particles that are removed from the paper surface are small in size, ranging from

190 to 25,000 µm² (Sudarno *et al*. 2007; Lestiani *et al*. 2013a). These particles mostly come from softwood and consist mainly of ray cells, fines, and fiber fragments (Lindem and Moller 1994). Other sources of lint may also include fillers and vessel elements from recycled fibers. All lint particles have low bonding potential in the paper surface (Wood and Karnis 1992).

The second reason why measurement of linting is difficult is that only a very small fraction of the paper surface is removed as lint. A set of measurements from sheet-fed and web-fed trials showed that only 0.0004 to 0.001% of the paper surface area was removed as lint (Sudarno *et al*. 2007). Many laboratory tests have overcome the problem of measuring the small amount of lint materials by greatly increasing the force applied to the surface to increase the amount of material removed (Batchelor *et al*. 2009). However, there is lack of correlation between the laboratory tests and the behavior of paper in commercial printing (Moller 1992; Hoc 2009). A large amount of paper, typically several thousand copies, must be printed in printing scale trials, in order to measure linting tendency of a paper. Such printing trials are extremely time-consuming.

The study of linting becomes complicated with the use of multi-color printing operations in modern commercial presses. In a four-color process or any multi-color printing, different inks are put in sequence in order to produce the final image. Linting then occurs as a result of the complex wetting and inking processes in each subsequent printing unit. In the first printing unit, lint consists of small fragments and weakly bonded particles that are loosened from the paper surface. Their origin is mainly from the slitting of the web into reels (Hoc 2000). The application of the fountain solution in each color printed may also weaken the surface of uncoated paper. This increases the likelihood that larger and well bonded particles will be removed later in the printing process (Sudarno 2006). It is difficult to predict how the character of lint will change as it passes through the multi-color printing operations, due to the different nature of lint particle size. However, Sudarno (2006) has shown that the last printing station of the four-color web press produced similar lint to a small single color sheet fed press. For that reason, this study will use a single color printing press to simplify lint measurement.

The complexity of a linting problem is compounded by the dynamic effects of lint migration, occurring on a printing press running at speeds of up to 10 m/s (Sudarno 2006). Lint particles that are pulled away from the paper surface can either be accumulated on the printing blanket or be transported further into the press or back to the paper. It is clear from earlier studies that both paper and printing press variables influence linting performance (Mangin 1991; Lindem and Moller 1994; Moller *et al*. 1995; Hoc 2000; Aspler 2003; Sudarno 2006). Nevertheless, the variety of different types of presses and materials used made it difficult to identify whether lint accumulation on the blanket originates from the paper or from the printing press variables (Hoc 2000; Wiik 2006; Hoc 2009).

Wiik (2006) has identified a mathematical expression for lint accumulation on the blanket that considers both paper and printing press variables,

$$L = (k_1/k_2)\times(1-\exp(-k_2\times n)) \qquad (1)$$

where k_1 represents the number of lint particles/m^2 that is released from the paper surface, k_2 signifies the probability per copy of a lint particle that is removed from the blanket, and n is the number of printed copies. This approach to characterize lint development is well supported by this study, the authors' previous work (Lestiani *et al*. 2013b, 2014), other researchers (Wiik 2006; Hoc 2009), and by experimental evidence of lint accumulation in the inking train after separating from the blanket (Heintze 2006).

To measure the dynamics of linting and to separate the effect of paper and press variables, a system consisting of a combination of video technology and image analysis must be used during printing. With this technology, the lint on the blanket can be monitored at each printing cylinder revolution in real time. Some other systems have been reported previously (Wiik 2006; Hoc 2009) on the dynamic measurement of linting. However, they still have some limitations. The first generations of the lint camera (Wiik 2006) had a problem with the illumination. The system was very difficult to set up and could not give reproducible results. In contrast, the Online Measurement System (Hoc 2009) produced superior image quality than the Wiik system due to faster shutter speed and better resolution. This measurement however, was done only with a light-colored ink that has been matched with the blanket color to produce visible white lint specks. There was also no information provided on test conditions such as ink tack.

The overall goal of our study was, therefore, to develop a measurement technique that measures lint dynamically, reproducibly with different press conditions including ink color. This system develops further the system presented in our previous study (Lestiani *et al*. 2013b), which was shown to significantly overestimate the lint area due to the blurring of the images from the rotating press and the non-uniformity of the illumination. The illumination problem has also been overcome in the current system and the set-up of the system has been modified to improve the reproducibility of results. Further details are shown in the components section of this study. The system also looked at different press conditions including ink color, to see how this relates to the lint migration during offset printing.

EXPERIMENTAL

Lint Camera System

The lint camera system that was developed consists of a camera, lens, LED lights, trigger system, and software for recording and measuring lint particles on the printing blanket. This entire system makes it possible to take pictures of the blanket at the same point during each revolution of the printing run. At the end of the printing run, the images of lint are analyzed using image analysis software.

Components

The camera used in the system is a NET Electronics GmbH Foculus FO232SB. The size of the image was 29.4 mm^2 and its image resolution was 96 dpi. The image size was determined by placing a ruler in the frame and having the camera sufficiently close to the blanket in a maximum magnification to take the picture. The lens is a NIKKOR AF Micro-Nikkor 60 mm f/2.8D and has a close focus distance of 21.9 cm. This is the distance to the image plane at the back of the camera. Image capture is triggered with an optical sensor that has polarizing filter and reflective tape (SICK Diamond Grade). The reflective tape is attached to a metal part of the printing cylinder, while the optical sensor is attached to the press frame, mounted at 90^o to the reflective tape.

The blanket is illuminated with a Schott LED Brightfield ringlight S80-25 that has an inner diameter of 66 mm and 80 white LEDs in 8 segments. The ringlight is attached around the lens of the camera to improve illumination of the imaging area. To achieve maximum illumination of 320 klux, the ringlight is placed 3 cm from the surface of the blanket. Furthermore, an extra LED light bulb lamp (5500K/DL 240V – 50 Hz) is also added at the bottom of the camera to give stronger illumination of the area photographed and to improve the contrast between the lint particles and the blanket.

The camera system is fixed to a steel rail, which is attached to an altazimuth mount (Manfrotto 516). The camera can be moved closer to the blanket along the steel rail to adjust zoom and focus in combination with the adjustable lens. The entire system is then mounted through the altazimuth mount to the press frame.

Printing Trials

The camera was tested on a Heidelberg GTO-52 press. This is a single color, sheet-fed offset press that can run at 8000 copies/hour and a speed of 1.2 m/s. The fountain solution used was 2% Aquarius AC, and the printing blanket was Seaga CMD2. Paper samples used for the trials were standard 42 gram per square meter (gsm), 45 gsm, 48.8 gsm newsprint and an improved newsprint of 55 gsm. More details of the samples have been given in an earlier study (Lestiani *et al*. 2014).

Three different ink colors were used for the experiments: a black ink with tack 12.5 from DIC, yellow ink with tack 14 from Toyo, and cyan inks with tack 9 and 13.5 also from Toyo. The tack values given in this study were reported by the manufacturer who supplied the ink. For each printing trial, the ink flow rate was targeted to obtain a solid print density of 1, as measured by a Gretag Densitometer. Two plates were used. The first plate was a standard A4 test plate consisting of solid, 40% tone at 150 lpi and non-image areas. The second plate was an A3 size plate with a solid in the top half and a 50% tone at 150 lpi in the bottom half of the plate.

The lint camera was positioned in front of the blanket and triggered to capture an image in the solid area of the printing blanket (Fig. 2). Only images from a solid area of the printing blanket were taken for the dynamic lint measurement because the half-tone pattern makes it difficult to separate lint particles by a threshold. An image was collected every revolution during the printing trial.

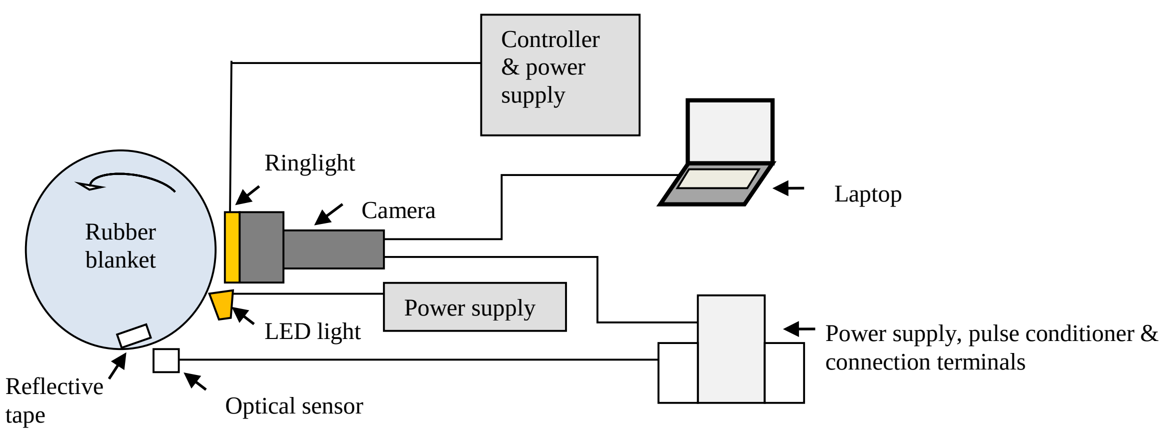

Fig. 2. Schematic diagram of the operational lint camera system

It is essential to validate the result of any new measurement technique. The results from the lint camera measurements were validated in two ways. For the large test plate, lint samples were collected at the end of each run by washing the blanket with 5% isopropanol solution, diluting it with deionised water and filtering the sample for image analysis (Lestiani *et al*. 2013b). For the small test plate, the dynamic images obtained towards the end of the press run were compared with the static images taken after the press was halted and with the pictures of the lint removed from the press blanket using adhesive tape after completion of the run.

Camera Exposure and Its Effect on Image Quality

Exposure time determines the amount of light that passes through the camera lens. Therefore, it is important that the chosen aperture and shutter speed are able to produce bright and non-blurred images. In practice, choosing the right settings has always been a challenge that affects the image quality and possibly also the accuracy of results.

To improve the appearance of lint particles, a shorter exposure time is chosen. This means that in a fast moving printing press, a faster shutter speed that has a short exposure time must be used to "freeze" motion and avoid blurring or noise in the background. An exposure of 100 µs has been used for all measurements here, as it provided sufficiently sharp images at the press speed used in the study.

Effect of Different Ink Colors Used in the Printing Trials

The ease of capturing clear images of lint during the dynamic of printing depends of the contrast between the ink/blanket colors. In a blue printing blanket, printing with either yellow or cyan ink will make the lint particles appear brighter than the blanket while, printing using black ink will make the lint appear as dark objects (Fig. 3). The image accordingly must be analyzed by thresholding on light objects for images A and B and dark objects on image C.

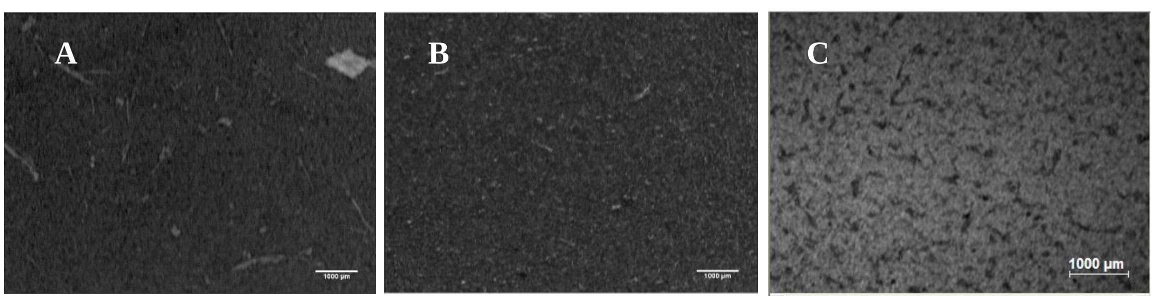

Fig. 3. The raw images from the lint camera system taken during the press run. (A) when yellow ink is used; (B) when cyan ink is used; (C) when black ink is used

Image Analysis

Filtered lint images

The acquired lint images from filtered samples were captured using an Olympus BX 60 optical microscope and processed using ImagePro 4.5 software (Sudarno 2006). The contrast between the lint particles and their background makes it possible to perform an automatic threshold on each image. Each particle is identified according to its size classes. Sixteen different area classes were assigned with a range of 1,600 µm². The final bin was set for particles with an area of 24,000 to 25,600 µm² (Lestiani *et al*. 2013a).

Image analysis was done to count the number of lint particles per image and to calculate the percentage coverage of lint particles on the blanket overall and with the different size classes. Furthermore, the size distribution obtained using this method is also calculated and compared with the results from the analysis of dynamic and static images.

Dynamic and static lint images

The dynamic (when the press is running) and static (when the press is halted) images taken by the lint camera were analyzed using ImagePro 4.5 software.

There are two steps to analyze the images from the lint camera system. First, any uneven illumination was fixed by flattening the image background. Flattening is an image analysis process for reducing non-uniformities in the lightness of the image background. Second, these images could not be processed using the automatic threshold available in ImagePro 4.5 software and so, a manual threshold was applied to identify the lint particles. The threshold always had to be manually adjusted due to a small degree of variability in the lighting from run to run, even under nominally constant conditions. For example: when conducting trials with black ink the threshold used was varied from 43 to 56. Figure 4 shows the results of dynamic and static images when automatic and manual thresholds have been applied. The thresholding techniques for image segmentation defined gray level boundary of a feature on a scale of 0 (black) to 256 (white). The lint particles are identified as dark objects on lighter blanket, and it can be seen that there was similarity in the area measured as lint for both dynamic and static images.

It is important to note that the same manual threshold was used for all images for a given run and that the variation in the threshold used was relatively small for runs on the same color ink.

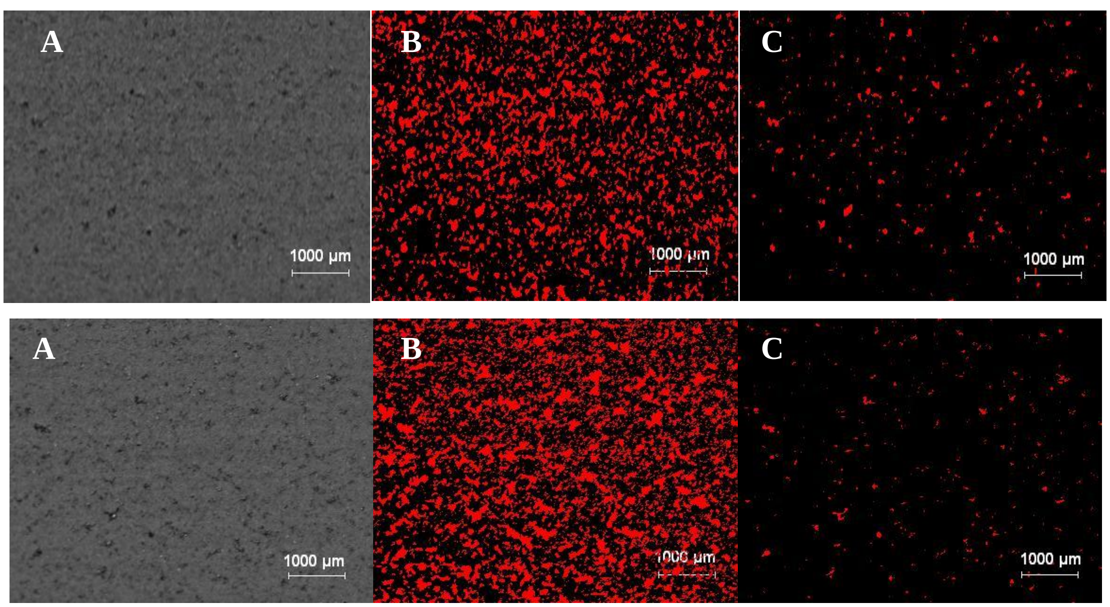

Fig. 4. Dynamic (top row) and static (bottom row) images of 42 gsm standard newsprint after printing 7000 copies at tack 12.5 acquired by the lint camera. (A) Raw images; (B) Image in (A) after applying an *automatic* threshold; (C) Image in (A) after applying a manual threshold of 54

The manual threshold is applied on dark objects when printing using a black ink. However, when printing with a yellow and cyan ink, the manual threshold is applied on light colored objects. Figure 5 compares the results from 42 gsm newsprint from one machine, printed using different ink colors. The results illustrate that although the threshold was done differently on lint particles when using black and cyan inks, the development of the corresponding lint curve was quite similar. Different ink colors should not affect the build-up of lint on the printing blanket. The rheological properties of ink (tack and viscosity) are more important and will influence linting performance.

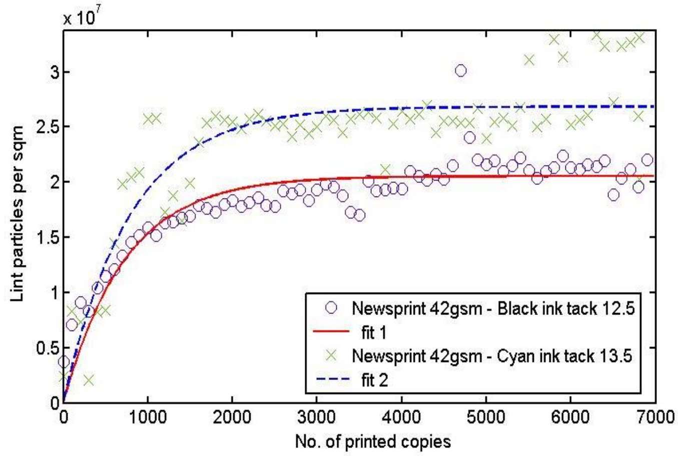

Fig. 5. Lint build-up on the blanket for 42 gsm newsprint, printed using black ink with tack 12.5 and cyan ink with tack 13.5

Tape pull lint images

A tape pull with an area of 68 cm² was used to collect lint from the blanket solid area after the press was halted. The lint images were observed under the Wild Heerbrugg M7A microscope and analyzed using ImagePro 4.5 software. The size of the image was 226.65 mm² and it has a resolution of 300 dpi. Similar to analysis of the dynamic and static images, the threshold setting was identified manually by visual inspection to distinguish the lint particles from their background (Fig. 6).

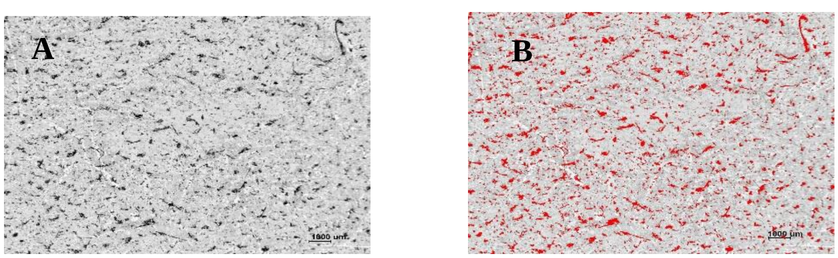

Fig. 6. (A) Raw lint images from the blanket tape pull; (B) Image in (A) after applying a manual threshold of 144

RESULTS AND DISCUSSION

Validation of the Lint Camera System

In Figs. 7 and 8, the distribution of the percentage area of lint on the blanket is plotted against the mean particle area. Figure 7 uses the data from 45 gsm and 42 gsm newsprint to show comparison from both the lint camera and the tape pull methods. The dynamic images were taken towards the end of the printing run, just before the ink was turned off and the static images were captured when the press was halted.

As can be seen, the correlation between the lint camera and the blanket tape pull method was very good. Both methods indicated similar trends, where the percentage area of lint distribution decreased with increasing particle size. This also means that the majority of lint released from the paper was comprised of small particle sizes.

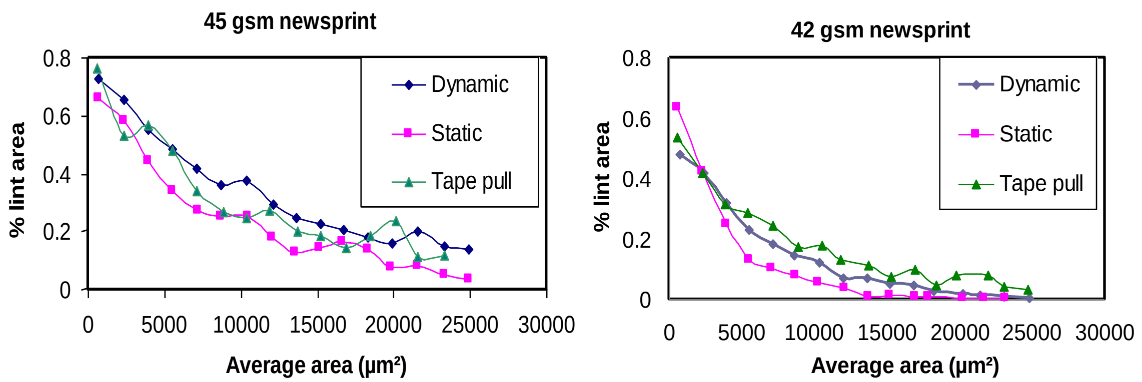

Fig. 7. The percentage area of lint distribution calculated from the blanket tape pull and from the lint camera on the solid area of 45 gsm and 42 gsm newsprint at tack 12.5. Both printing trials were done using the standard A4 test plate.

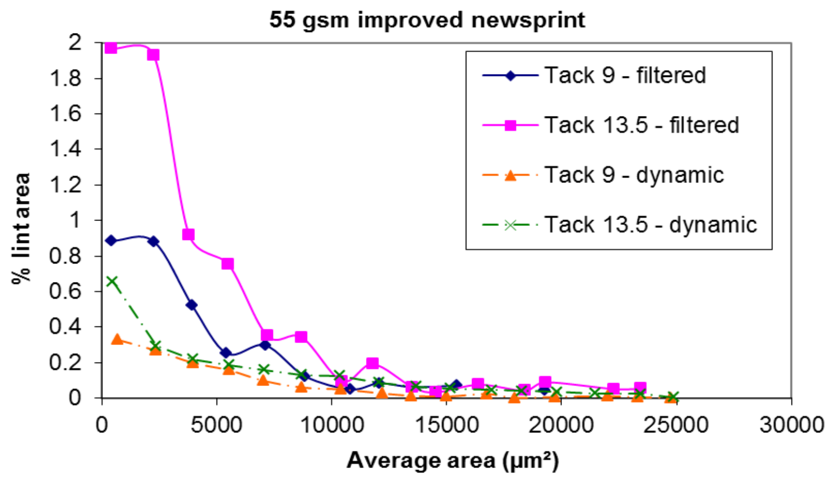

Fig. 8. The percentage area of lint distribution obtained from washing the lint from the blanket and from the lint camera on the solid area of 55 gsm improved newsprint at tack 9 and 13.5. These printing trials were done on the A3 size test plate.

Figure 7 compares the percentage area distribution of lint from the lint camera with the area distribution from the filtered samples obtained by washing the blanket, when printing improved newsprint either with tack 9 or with tack 13.5 ink. For larger particle sizes, the distribution was similar in shape to those shown from the lint identified by the blanket tape pull. However, data for the filtered samples indicate that the percentage area distribution at small particle sizes was higher than the area distribution of lint particles obtained from the lint camera and from the tape pull. This was due to i) agglomerated lint particles that are disaggregated by washing and filtering, and thus are being measured as more of smaller particle sizes and ii) the higher resolution of the microscope, which allows it to detect smaller particles.

The following table shows the solid and screen lint weight measurements from the tape pulls, taken after the printing trials. As can be seen in Table 1, the lint weight measurements for the four newsprint samples were quite variable. For the 45 gsm newsprint, the solid lint weight value was a little odd, as the solid lint weight was much lower than then screen weight, while for the other three measurements the solid lint weight was 82.5 to 86% of the screen weight. This evidence shows that a single lint weight measured from tape pulls at the end of the run may not give reliable results, as it only measures part of the lint that has been removed from the paper surface. It also underestimates the lint accumulation in a commercial length print runs, which will be much longer. Sudarno (2006) has studied the relationship between the tape pulls lint weight and the filtered lint samples obtained by rinsing the blanket. However, the data shown were scattered and there was about 5 to 30% weight discrepancy between the filtered sample and the tape pulls (Sudarno 2006). Because of this inconsistency, the use of a lint camera system to capture the lint build-up during printing run is considered a better option to study lint removal from the paper and from the blanket.

Table 1. Solid Lint Weight Values Measured from the Tape Pulls

Paper samples	Ink Tack	Solid lint weight (g/m^2)	Screen lint weight (g/m^2)
Newsprint 42 gsm	12.5	2.53	2.94
Newsprint 45 gsm	12.5	0.51	3.26
Improved newsprint 55 gsm	9	1.47	1.78
Improved newsprint 55 gsm	13.5	1.73	2.98

Variability Analysis

In order to assess the variation of the test due to the dynamics of image capture, standard printing tests were conducted under controlled conditions. A series of 2000 images of the same solid area of the blanket were taken when the plateau was reached. Figure 9 shows the variation in the number of lint particles/m² reported on the printing blanket when printing 42 gsm newsprint using black ink with tack 12.5. The mean number of lint particles/m² identified was 1.41×10^7. The standard deviation was 7.08×10^5 and the coefficient of variation was 5%.

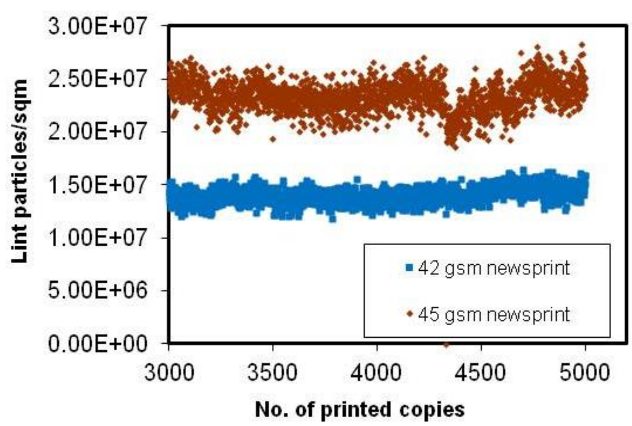

Fig. 9. Variation in the number of lint particles/m² when the same solid area of 42 gsm newsprint at tack 12.5 and 45 gsm newsprint at tack 13.5 was imaged under dynamic conditions

Figure 9 also shows the amount of lint found on the blanket after printing 45 gsm newsprint using cyan ink with tack 13.5. In comparison to 42 gsm newsprint, the 45 gsm newsprint gave larger variation in the run. The mean number of lint particles/m² was found to be 2.34×10^7, with a standard deviation of 1.54×10^6 and a coefficient of variation of 6.5%.

The results indicate that the value for coefficient of variation will likely vary for different types of newsprints, ink tacks, and for different thresholds used in the analysis. Variations between papers are related to different paper properties. Careful review of successive images showed that the variation under dynamic conditions is likely due to lint particles that are going onto or leaving the blanket. For that reason it was judged that the uncertainty due to imaging process is very small.

Application of Lint Camera on Paper Variability

The effect of paper variability on the behavior of lint build-up on the blanket can be observed using the lint camera system. Figure 10 shows an example of lint build-up from three different newsprints. These papers were manufactured from two different paper machines using thermomechanical pulp (TMP). The amount of calcined clay added to improve the sheet opacity would be 0% for 48.8 gsm newsprint, approximately 3% for 42 gsm newsprint, and about 1 to 2% for 45 gsm newsprint.

The data were fitted with Equation (1) with k_1 and k_2 as the fitting parameters. Although some data sets were scattered, the fitted statistics were reasonable. Their fitted parameters and its statistics are shown in Table 2.

Table 2. Fitted Parameters for Data in Figure 13 Calculated from Equation (1)

	$k_1/10^3$	$k_2/10^{-4}$	R^2
Newsprint 42 gsm	7.28 (6.55, 8.02)	4.58 (3.89, 5.25)	0.93
Newsprint 45 gsm	26.52 (22.68, 30.36)	12.83 (10.79, 14.86)	0.79
Newsprint 48.8 gsm	6.44 (5.84, 7.04)	2.29 (1.81, 2.77)	0.96

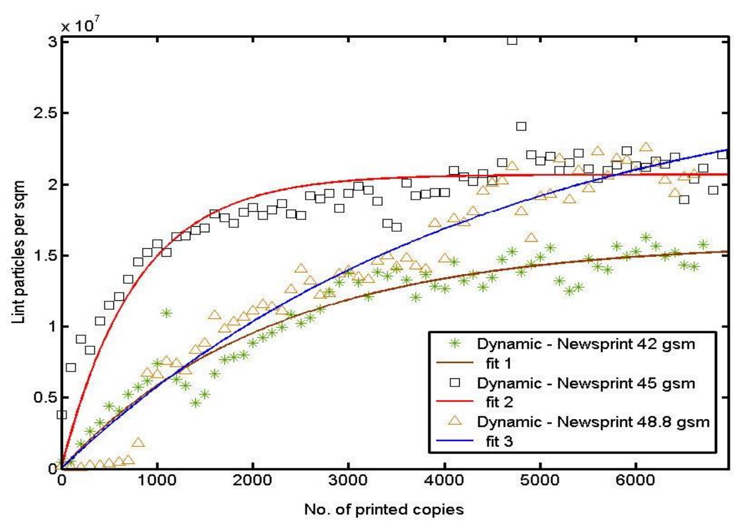

Fig. 10. Lint build-up on the blanket from three different newsprints manufactured on two different paper machines

Figure 10 shows that the lint produced by the 45 gsm and 48.8 gsm newsprint samples were similar. Both produced higher lint than the 42 gsm newsprint sample. However, if the lint measurements were taken after printing 2000 copies, 42 gsm and 48.8 gsm newsprint samples were the ones that produced similar lint, while the 45 gsm newsprint sample produced the highest lint. These results indicate that the sample with the most lint measured will depend on the number of printed copies. That is why a measurement based on a single point at the end of the run will give an incomplete picture, as it does not consider the removal of lint particles from the blanket. In order to get the true picture of linting process, measurement of lint particle dynamics needs to be carried out. The dynamic lint measurement makes it possible to quantify both lint removals from the paper and from the blanket. Such information will be useful to identify the effect of paper and printing press variables on linting performance.

CONCLUSIONS

1. The latest development of the lint camera system and its applications in various printing tests has been described in this paper. The camera system is capable to dynamically measure lint with different color printing inks.
2. The area distribution of lint measured by the camera show similarities to the lint area distributions measured from the blanket tape pulls. On the other hand, the percentage area distribution at small particle sizes from the filtered sample is found to be higher compared with the measurement from the lint camera during the run. This could be due to agglomerated lint particles that are disaggregated by washing and filtering.
3. Under stable conditions, where overall lint deposits and removals from the printing blanket are in equilibrium, 5% to 6.5% variation around the measured average number of lint particles was observed. This was due to the random deposition and removal of lint particles.

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