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FUNDAMENTAL STUDIES OF LINTING IN OFFSET PRINTING OF NEWSPRINT

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ABSTRACT

Linting is the removal of material from the surface of uncoated grades of paper during offset printing. Excessive linting reduces image quality and can reduce press productivity. In this paper, web-fed and sheet-fed linting trials have been used to investigate the effect of important press and paper variables on linting. Two of the most important printing parameters affecting linting were the take-off angle from the nip and the printing tone. From analysis of the effects of take-off angle and printing tone, two forces were identified as being especially important to linting: a film flow force in the nip and a tack force from the splitting of the ink film. A simple model was presented that could qualitatively explain why printing press speed, printing pressure and ink tack all had smaller effects on linting than would be expected from consideration of tack force alone. Laboratory printing tack tests and other measurements of paper properties were compared with lint measured in the sheet-fed trials. The tack force measured in laboratory printing was found to be lower for improved newsprint compared to newsprint, while the lint in both sheet-fed and web-fed trials was higher for the improved newsprint. Differences in the film flow in the nip were suggested to be responsible for both effects. The improved newsprint was also found to have a lower surface strength, as measured by delamination.

INTRODUCTION

Offset lithographic printing works by first transferring a layer of fountain solution to the printing plate, followed by a layer of ink. Ink and fountain solution are then transferred to the printing blanket and then printed to the paper substrate. Ink is transferred on the printing plate only if the adhesion force between the ink and the plate is greater than the ink cohesion [1, 2]. Ink is transferred to the image area because the image area is hydrophobic and does not accept a layer of fountain solution. Ink does not transfer to the non-image area because the non-image area is hydrophilic and the film splits in the layer of fountain solution that is applied before the ink. Fountain solution is water with a small fraction of surfactants and other wetting agents. Coldset offset lithographic ink normally consists of 20% carbon black, 5% alkyd resin, 5% vegetable oil, 10% hydrocarbon resin and 60% mineral oil.

Linting is considered to be one of the more serious problems in the offset printing of newsprint [3]. It is defined as the removal of material from the surface of the paper and accumulation on the blanket and also on the plate. Image degradation starts to appear when a considerable amount of lint has accumulated on the blanket or smaller amounts on the plate. This degradation is more likely to occur as the lint particle size increases. Lint from softwood TMP is composed of three different types of particles – fines, fibre fragments and ray cells [4]. Other sources of lint include filler particles and vessel elements from recycled fibres containing hardwood pulps. Almost all lint particles are less than 25,000 μm^2 in size [5, 6].

Despite considerable effort, there is no easy means to predict the linting from a given paper in a particular press. One major difficulty is the very small area of the paper surface typically removed as lint. Measurements from sheet-fed and web-fed trials showed that 0.0004 to 0.001% [6] of the paper surface area was removed as lint. Methods that can be used to characterise linting can be divided into laboratory tests and actual printing trials [7]. A large number of laboratory tests have been developed but no test has been adopted as a standard. Laboratory tests typically apply much larger forces to the surface than the offset printing process, in order to remove large areas of the surface as lint. Tests are either run to measure the area removed as lint or the point of delamination of the surface. In contrast, printing trials typically involve printing several thousand copies on small commercial presses and measuring the lint accumulated on the blanket. A number of different presses have been used [7–9]. Lindem and Moller [10] compared a small offset press and a range of laboratory tests with full scale printing trials on a commercial press. None of the test methods correlated well with the lint from the full scale commercial trials.

The simplest method of measuring lint is to remove lint deposited on a blanket with a tape and measure the increase in weight of the tape. It is also possible to use a microscope to image the lint particles on the tape [11]. Heintze and Ravary [12] described washing the lint from the blanket and collecting it before filtering the lint through 150 and 400 mesh screens to measure the weight of the large and small lint, respectively. Sudarno *et al.* have modified this technique by collecting the lint particles on filter paper and measuring the lint particle area through microscopy and image analysis [13].

The character of the material removed from the paper in offset printing has changed. 30 years ago, the lint was much larger and typically consisted of large fibre fragments, fibres and shives [14]. Improvements in furnish and papermaking have reduced linting and greatly reduced the size of lint particles. The linting of large TMP fibres has been reduced with improvements in mechanical pulping to increase the bonding capacity of the fibres and reduce the shive content of the pulp [14]. The transition from fourdriniers to gap formers has also reduced linting [15], due to the better surface consolidation of the paper and reduced two-sidedness achievable in gap formers. Higher press loads on a pilot machine were also found to improve linting [16], due to better surface consolidation.

The forces on the paper surface that produce lint have been divided into two forces acting in the nip, a free ink film flow parallel to the direction of web motion and a porous ink film force, and a third force, called the tack force, arising from the splitting of the ink film after the printing nip [17]. A schematic diagram is shown in Figure 1. It should be noted that the thickness of the ink film relative to the paper has been greatly exaggerated. The tack force at the exit of the printing nip is not the same as the nominal ink tack, typically reported by the manufacturer, which is the torque required to rotate a set of rollers at a fixed speed when covered by a prescribed weight of ink.

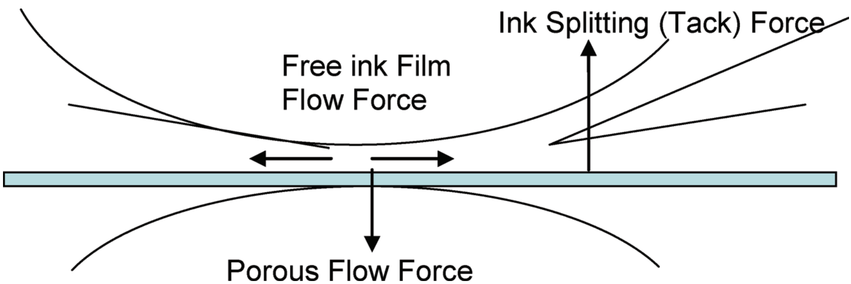

Figure 1. Schematic diagram of forces applied to the paper surface in the printing nip.

In contrast to the forces in the nip, the tack force can be measured as the ink film splits at the exit of the printing nip. The main challenge is to measure forces over the short time-frame of printing. One approach used a small pressure transducer embedded into one of the two cylinders on a laboratory printing press [18]. Tack was calculated as the maximum negative pressure (tensile force) on the sensor as it exited the printing nip. Another variation on this idea has been a recently developed laboratory instrument, the Deltack. This instrument measures the tension required to pull a test strip away from a printing cylinder as it exits the printing nip [19]. Most applications to date have been for the measurement of the build-up of tack on coated papers [19]. Another approach has been to calculate the work of adhesion of the ink film from the take-off angle and tension in a web-fed offset press [20]. The research showed that coated papers produce much larger work of adhesion than uncoated papers. Printing tack is not the same as ink tack, although they are related.

The printing press variables related with lint have been reviewed in [21, 22]. Generally in a web-fed press the paper does not exit the nip at 90° to the direction of nip loading, contrary to the situation shown in Figure 1. Waech has shown for single sided printing that there is much less lint if the paper exits the nip and is wrapped around the blanket roll, compared to if it is wrapped around the impression cylinder [11]. The differences were ascribed to a change in the splitting rate of the ink film. Another variable widely agreed to affect lint is the printing tone, the area of the printing plate covered by ink dots, ranging from 0 (non-image area) to 100 (solid). Observations have typically shown a maximum of lint with tone in the middle of this range [11, 21, 22], although the data show no agreement as to the tone at which the maximum occurs. One explanation offered has been that the extra fountain solution in the half tone areas weakens the paper, thus increasing lint in those areas [22], although this seems unlikely due to the very short time frames involved in passage through a typical printing nip. The effect of both printing pressure and press speed are unclear. Some press trials reported a small increase in lint with speed, while others reported no change [21]. The same was true for printing pressure. It is clear that while there is some general agreement as to the important press variables affecting linting, the fundamental mechanisms still require further elucidation.

The purpose of this paper is to use carefully conducted web and sheet-fed printing trials, measuring lint weight and lint particle size, to investigate the major printing variables affecting linting. These measurements are matched with laboratory measurements of sheet properties to examine whether measurements of paper properties can correlate with linting under constant printing press conditions.

EXPERIMENTAL METHOD

Three different grades were used in the experiments. Most of the testing was done on 52 gsm improved newsprint with an ISO brightness of 74. Improved newsprint is labelled 'improved' due to the increased brightness, which is achieved by increasing the bleaching of the pulp and by increasing the filler content. Some additional testing was done on two different 45 gsm newsprints. The first newsprint, labelled newsprint A, was manufactured under similar conditions to the improved newsprint, using a horizontal gap former with similar fibre furnish, predominantly radiata pine TMP, with smaller components of a hardwood semi-chemical and a recycled fibre pulp. Both of these samples were produced by Norske Skog Australia. The second newsprint, labelled newsprint B was produced at a European mill with an approximately equal mixture of recycled fibre and softwood TMP.

Lint was measured for both web-fed and sheet-fed printing trials. Each web-fed trial required several rolls of paper. For each trial, the rolls were selected so that they were manufactured within a few days of each other. For the sheet-fed trials, the paper was cut to A3 size from a single roll for each trial.

The web-fed experiments were conducted on a Man-Roland Uniset press, which is a 4-colour web-fed coldset offset lithography printing press, with a maximum speed of 30,000 copies per hour. This press has 5 printing units, each with two pairs of printing couples. The press has six reel-stands so that different web arrangements can be achieved, such as arranging top and bottom side of the paper and varying the printing nip take-off angle. In odd numbered reel stands, the bottom side of the paper is located on the left hand side while in even numbered reel stands, the bottom side of the paper is located on the right hand side, as observed from the control room. Top/bottom side of the paper means the top/bottom side of the paper as it was produced on the paper machine. The first three printing units were used in the trials. The first printing unit consists of two printing couples, i.e. top printing couple and bottom printing couple. Due to the web configuration, the top printing unit has a 102° take-off angle for the top side of the paper while the bottom side has a 78° take-off angle. Angle is defined here as a vertical line through the print couple having a take-off angle of 90°. The bottom printing couple bottom side of the paper has a 153° take-off angle while the top side of the paper has a 27° take-off angle. The couples and their web leads are shown in [5, 23] and a schematic diagram illustrating take-off angle is shown in Figure 4. The large difference in take-off angle was due to the web-lead chosen rather than the normal web-lead used on the press. In the standard trial configuration, the press was run at 25,000 copies an hour. Neither ink nor fountain solution consumption could be measured. Instead the ink and fountain solution were adjusted to achieve a solid print density of 1.0.

Three full trials were conducted. Lint was measured after 40,000, 23,000 and 25,000 copies in the first trial, second and third trial, respectively. The first trial investigated the effect of paper type (improved newsprint, newsprint A and B), paper orientation (clockwise/anti-clockwise unwind), paper side (top and bottom side), printing tone and the effect of first and subsequent printing units. Only the 78°/102° combination of take-off angles was used in these trials. Analysis of the data showed that the take-off angle had an unexpectedly strong effect on lint. Therefore the second trial investigated take-off angle by altering the web-leads on the top printing unit. Other variables tested included paper side, ink tack, printing tone, ink colour and number of copies. The third trial investigated ink tack, printing tone, take-off angle and printing pressure. Except for some measurements in the first printing trial, all other experiments measured linting after a single colour printing. Only improved newsprint was used for the second and third trials. Each experiment had six separate areas on the printing plate with different printing tones and lint was measured in each area. A multi-factorial experimental design was chosen due to limited press availability. Thus there are no independent measurements of side or take-off angle, where all the other variables were held constant. More details of the experiments are given in [23].

The sheet-fed experiments were performed using a sheet-fed Heidelberg GTO-52 printing press. This is a small single colour, single side sheet-fed offset press that can run a maximum size of A3. The estimated take-off angle of the sheet from the impression nip was 70°. A speed of 8000 copies per hour and a nip pressure setting of 0.05 was used, unless otherwise stated. Nip pressure was measured using Fuji prescale pressure sensitive film taped to the blanket. The nip pressure setting gave a nip pressure of 3.4 MPa, although it should be noted that this changed somewhat over the life of the blanket, as the blanket compacted.

To start up the machine, ink and water were run for a period of 60 seconds in order to achieve stable emulsification. The volume of fountain solution used (5% fountain solution concentrate in distilled water) was measured and controlled during printing by recording the volume of fountain solution in a reservoir. The ink weight applied for each impression could not be measured. Instead a solid print density of 1.0 was targeted for each trial. The standard experiment printed 7000 copies of an A3 size sheet, with solid in the top half and 50% tone, at 150 lines per inch, in the bottom half of the plate.

Two sets of sheet-fed trials were run. One set was used to test press and print variables. The data from this set are reported with the data from the web-fed experiments. The second set was used to examine the effect of sheet properties on linting. These experiments all used the standard set up with a tack 13.5 black coldset ink, measuring lint on the top side of the sheet only. All sheet-fed trials used improved newsprint.

Both cyan and black coldset inks were used for the trials. The tack values given in the text are those reported by the manufacturer. The shear viscosity of each of the inks was measured with a Porepoise Capillary Rheometer. This instrument consists of two pistons, a barrel with nitride hardened bore and pressure transducer port and a computer to control the instrument. One piston is used for the measurements and the second for an error discrepancy calculation. Viscosity is measured from the pressure developed during the test. Apparent shear viscosity was measured at apparent shear rates up to $2 \times 10^5 s^{-1}$.

Two methods were used to measure lint. At the end of printing trials, adhesive tape with an area of 68 cm^2 was used to collect lint by sticking it onto the blanket with a roller. The press was run for a number of copies without application of ink to remove free ink from the blanket before collection. The weight of the tape before and after lint collection was noted so that the lint weight per unit area of blanket (given as g/m^2) could be calculated.

Lint was also collected from the blanket using a brush and 5% isopropanol in water solution. The sampling method involved wetting the blanket with isopropanol solution and brushing vigorously. The isopropanol solution and lint was then captured in a 30 × 10 cm curved frame pressed against the blanket. Different frames were fabricated to match the radius of curvature of the blanket cylinders of each of the web-fed and sheet-fed presses. After collection, the sample volume was adjusted first to either 100 or 200 ml. 1% by volume (1 or 2 ml) was then filtered through Mixed Cellulose Ester filter paper. An Olympus BX 60 light microscope was used with 5X magnification to capture images of the lint on filter paper. 20 images were captured for each sample. Prior to capturing the images, a white balance operation was performed using a clear paper. Each of the images covers 7.6 mm^2 out of 1134 mm^2 of the total filter area. Image Pro 4.5 was used to identify and analyse lint particles according to area, using an automatic threshold. Figure 2 shows an example of the lint particles in an image that have been identified by the software. The software has the limitation that it can only sort particles into a maximum of 16 classes. The lint particles were put into bins with a range of $1000\mu m^2$, thus the first bin was for particles $0–1000\mu m^2$, the second for lint particles of size $1000–2000\mu m^2$ up to $14{,}000–15{,}000\mu m^2$. The final bin included all particles above $15{,}000\mu m^2$.

Samples from eight rolls of improved newsprint and seven rolls of newsprint A were selected for testing of paper properties for comparison with

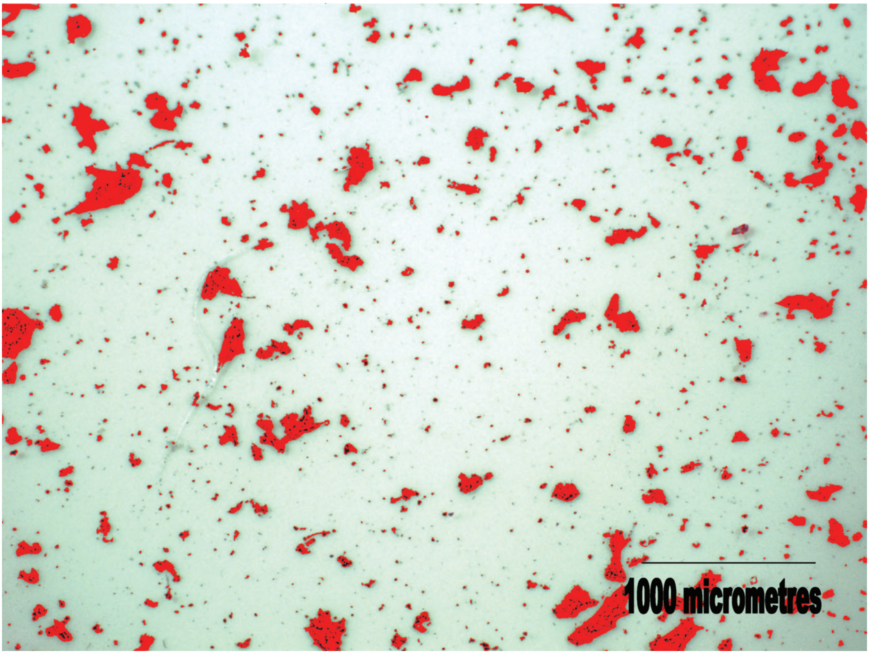

Figure 2. Image analysis identification of lint particles.

solid and 50% tone linting data measured on the sheet-fed press. Only the top side was tested for both linting and paper properties.

A Fibro FRT 100 Fibre rising tester was used to examine the surface reactivity to the addition of water. The test measures weakly bound fibres that lift from the surface in the presence of water and/or heat [24]. To conduct the test, 7 g/m^2 of water were applied to each sample in the test after which the sample was moved around a bend and the number, length and area of fibres lifted from the surface by the application of water was measured. Each value reported is the average of three tests each in the machine and anti-machine directions. Because of a shortage of samples, two improved newsprint samples were not measured for fibre rising.

The surface strength was measured using a procedure developed by Zhao and Pelton [25, 26]. The sample was mounted on a rigid plate attached to the fixed jaw of a tensile tester. A tape was adhered to the surface under constant pressure and attached to the movable cross-head of the tensile tester to create a 180 degree peeling geometry. The surface strength was measured as the point of maximum force before the surface began to internally delaminate. Three tests were done in each of the machine and anti-machine directions for each sample.

Printing tack force was measured using a Prüfbau Deltack [19]. This consists of an inking unit and a printing unit. The printing unit has a larger central cylinder with a smaller printing cylinder. The paper strip for testing is prepared for mounting by reinforcing the ends of the strip with tape and then punching holes in the strip. The holes are then used to attach the test strip to pegs mounted on the central cylinder. One of the pegs is attached to a sensitive force transducer, which measures the tensile force in the strip as paper is pulled away from the printing cylinder at the exit of the printing nip. Tack was measured by extrapolation to a speed of $0.75 ms^{-1}$, chosen so that the ink-film splitting rate best matched that of the sheet-fed press [27]. The ink used for testing was the same black tack 13.5 ink used on the sheet-fed press and the ink weight applied in printing was adjusted for each sample to give a print density of 1.0. During each test the measured force started at 0 and increased until reaching a plateau value, which was taken as the printing tack force. Each reported point is the average of three or four measurements.

Surface roughness was measured using a Bendtsen roughness tester, while average bulk pore size was measured using mercury porosimetry.

RESULTS

The reproducibility of lint measurements is typically poor. An example is show in Table 1 from web-fed trial 1, comparing the two newsprint samples with the improved newsprint, printing magenta, cyan, yellow and black in sequence. The results for 20% tone and solid are shown in Table 1. Despite the printing of a monotone pattern, it can be seen that the results are very variable, with the best performing sample (least lint) varying from measurement to measurement. From these results alone it is difficult to determine what factors are controlling the amount of lint.

The data indicate the importance of not relying on any individual measurement. Instead our approach has been to statistically analyse the web-fed trials to determine the most important variables. The major statistically significant variables contributing to linting were take-off angle, printing tone, paper side, paper, press speed and ink tack. All of these printing and paper variables, except for paper side, are discussed in detail in this report.

One of the most important effects was take-off angle. Figure 3 shows the effect of take-off angle combined with paper side for the second web-fed printing trial. These results were measured on improved newsprint, as are all

Table 1. Lint weight measured by tape pulls on each of the blankets for four colour printing of the 20% screen area and the solid print.

	Improved News Lint(g/m²)	*Newsprint A Lint(g/m²)*	*Newsprint B Lint(g/m²)*
20% tone			
Magenta	3.8	4.4	0.7
Cyan	2.0	1.2	2.9
Yellow	2.6	2.4	5.1
Black	1.9	2.9	2.7
Solid			
Magenta	1.8	1.6	2.2
Cyan	1.7	0.7	0.6
Yellow	1.0	0.6	1.3
Black	1.4	1.1	1.4

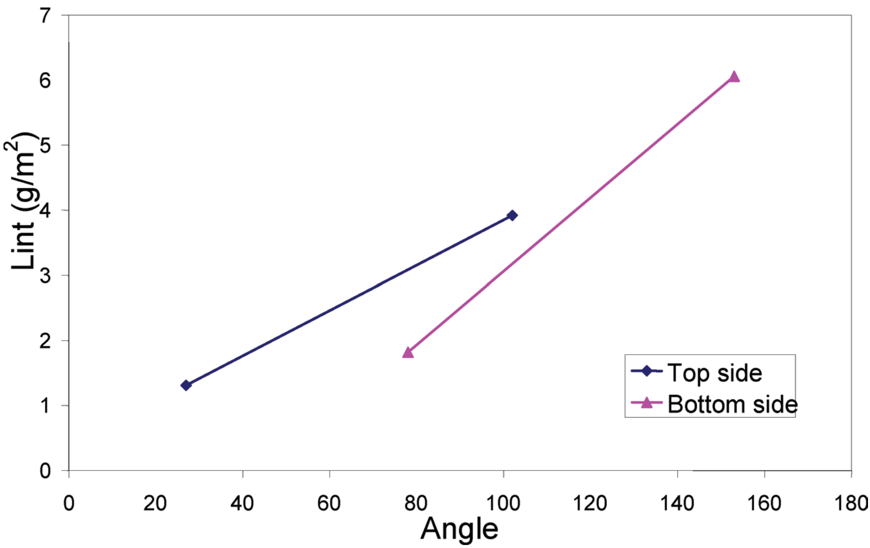

Figure 3. Average lint as a function of take-off angle for the second web-fed printing trial.

other results in this paper, except where otherwise noted. These results were generated by averaging all of the data obtained for each take-off angle and paper side. Thus each point shown here is the average of fifteen data points, as five screen tones and three different tack inks (6, 9 and 13.5) were tested for each combination of take-off angle and paper side. The critical importance of take-off angle and paper side acting together is indicated as the highest average lint result (bottom side with take-off angle of 153°) is approximately five times the smallest average lint result (top side with take-off angle of 27°). The data also shows that the top side of the paper gives more lint than the bottom side.

Figure 4 is a schematic figure showing a paper web running between two printing blankets. The figure ignores any vertical offset of the cylinders, which may affect how the paper exits the nip. Take-off angle is defined as 90° when the paper is running vertically. This figure shows two cases. The left hand side shows a print couple with a 90° take-off angle on both sides, while the right hand side shows a print couple with approximately a 45° take-off angle on the right hand side and a 135° take-off angle on the LHS.

Our initial hypothesis for the effect of take-off angle was that it was due to an increase in the tack force that in turn was due to an increase in the ink film splitting rate. Effects of take-off angle are unlikely to be due to flows in the nip- i.e. the film and porous flow force described by Mangin [17], since these should not depend on the web path after the web leaves the nip.

This hypothesis was investigated by measuring printing tack force as a function of printing speed. Figure 5 shows results for samples from three different rolls each of newsprint A and improved newsprint. Tack force increases approximately linearly with printing speed for all samples. Both the

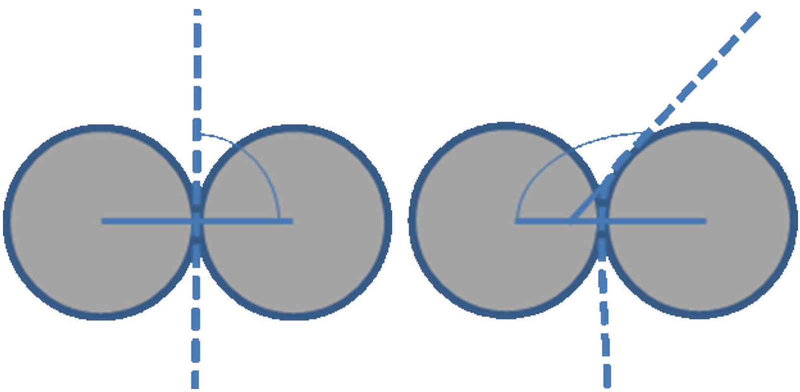

Figure 4. Simplified schematic showing different take-off angles in a printing press.

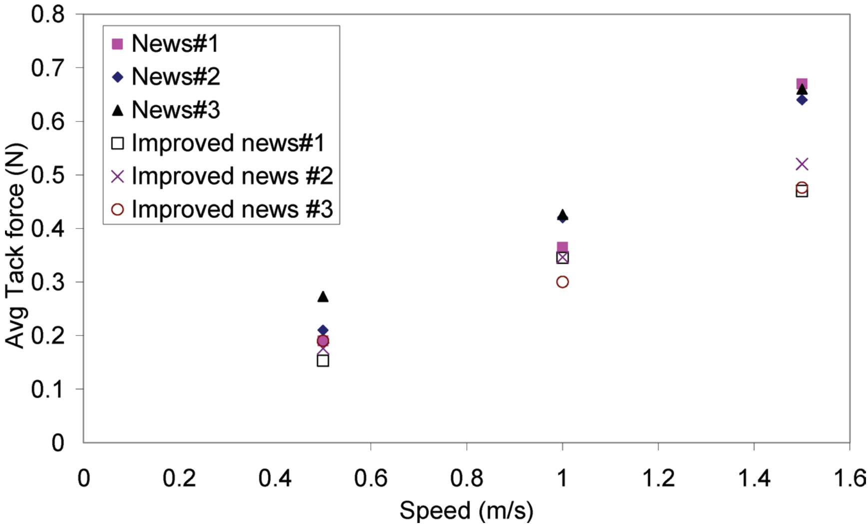

Figure 5. Printing tack force measured for three samples each of improved newsprint and newsprint A.

newsprint and the improved newsprint data are also consistent within each data set, with the improved newsprint samples having a consistently lower tack force than the newsprint samples at all speeds. The increase in tack force with print speed arises from an increase in the force required to split the free ink film as speed increases, as there was no statistically significant difference between ink weight transfer between improved newsprint and newsprint A, for the same applied ink weight. Assuming the same bond strength per unit area, then if the forces are higher, larger particles will be removed. Similarly, a higher fraction of larger particles implies higher forces have been imposed on the paper surface.

Figures 4 and 5 shows that the tack force measurements can qualitatively explain the difference between a 45° take-off angle and a 135° take-off angle, as the rate at which the ink film splits will be double at a take-off angle of 135° in comparison to 45°. The tack force measurements in Figure 5 suggest that doubling the ink-film splitting rate will also double the force applied. The difficulties with the hypothesis come when we compare a take-off angle of 90° with 45°, because in both cases the paper leaves the cylinder at a tangent to the cylinder, thus the ink-film splitting rate should be the same. The increase in lint in Figure 3 when the take-off angle is increased from 27° to 78° cannot be explained as a change in tack force due to an increase in the ink-film splitting rate, since the ink-film splitting rate should be the same, and only determined by the diameter of the blanket cylinder.

We suggest that there are two effects involved in producing the observed effect of take-off angle. Take-off angles over 90° compared with take-off angles under 90° should have twice the ink-film splitting rate and, if the printing tack measurements directly translate to the press, twice the tack force. From this stand-point, the tack force and lint should be independent of take-off angle at high take-off angle and only determined by the rate of separation of the two cylinders in the nip. This hypothesis is consistent with literature data of a previous study of single-sided printing between a blanket with ink and impression cylinder, which showed that an initial increase in lint when the angle of the sector of wrapping around the impression cylinder was changed from 0° to 20°, but no further change in lint when the wrapping angle was further increased [11].

However ink film splitting rates cannot explain the reduction of lint at the lowest take-off angle of 27°. This is likely to be due to visco-elastic effects from the additional residence time of the ink film on the cylinder before the ink film is split. Printing inks in the nip are subject to squeeze flows and shear over very short time frames. Inks, like all polymer suspensions will display transient behaviour following a rapid application of force. Inks are also known to display thixotropic behaviour, where the apparent viscosity decreases when held under a constant force. We suggest that the increase in residence time on the cylinder as the take-off angle is reduced will allow the polymers to begin to unlock in suspension, reducing the apparent viscosity and the tack force.

The printing tack measurements cannot measure the effect of this additional residence time low angle although they can explain the difference between a high take-off angle and one around 90°. Finally, it should be noted that it is difficult to explain with this analysis the differences between take-off angles of 78° and 102°. A complicating factor with these take-off angles is a slight vertical offset of one cylinder from the other. This combines with the tension in the roll and film splitting occurring on both sides almost simultaneously to make analysis of the exact path of the web difficult.

The next important printing effect on linting to consider is printing tone. Table 2 summarises all available measurements conducted as part of this research.

The data show considerable variation between data sets, but most data sets show a maximum in measured lint between 20% and 50% printing tone. Generally the solid (100% coverage) has the lowest lint, with the non-image area lint being intermediate between the solid and 25 or 50% tone. The data

Table 2. Effect of printing tone on lint. The numbers give the average lint weight from tape pulls in g/m^2.

Trial No	*Variables Averaged*	*Points Averaged*	*0%*	*20%*	*25%*	*50%*	*75%*	*100%*
Web-fed 1	Take-off Angle, Paper Side of Newsprint A	8	2.59	3.71		2.56	1.54	1.18
	Take-off Angle, Paper Side	8	1.75	3.00		2.10	1.33	1.05
	Take-off Angle, Paper Side of Newsprint B	8	2.83	3.32		3.10	1.90	1.21
Web-fed 1	Take-off Angle	8	1.94	3.98		2.86	1.47	2.50
Web-fed 2	Colour, Screen Ruling, Take-off Angle	8			3.15	3.04		
Sheet-fed	Nip Pressure, Blanket Age	7				3.36		2.00
Web-fed 3	Nip Pressure, Blanket Age, Take-off Angle, Paper Side	8	2.36		2.89	2.32	2.13	1.85
Web-fed 2	Number of Copies, Tack, Ruling, Side, Take-off Angle, No. of Copies	12			2.70	2.67		
Web-fed 2	Ruling, Side, Tack, Speed	16			3.20	2.80		
Sheet-fed	Speed, Side	7				2.47		1.42
Web-fed 2	Water Setting for Bottom Side of the paper	4	2.73		3.23	2.71		1.57
Web-fed 2	Water Setting for Top Side of the paper	4	3.25		5.13	4.76		2.82

are consistent with the general trends reported in the literature [22]. It remains an open question as to what can explain these trends.

To investigate this further we looked at lint particle size data. Two sets of data are shown in Figure 6 and Figure 7. Both data sets were from the third web-fed trial. We would expect that larger forces would be associated with larger lint particles. Figure 6 shows the % area on the blanket of the lint collected as a function of printing tone for printing the top side with a black tack 13.5 ink. The take-off angle was 27°. Figure 7 shows the comparable measurements for the lint on the reverse side of the sheet with the same ink and a take-off angle of 153°. The data in both figures has a parabolic shape because the software is limited to sorting into only sixteen size classes and

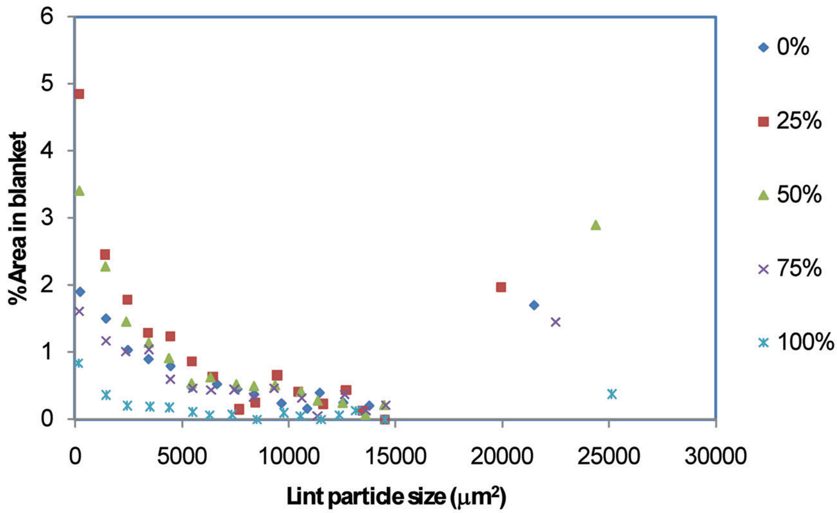

Figure 6. % area of lint particles on the blanket for printing the top side of the paper with tack 13.5 black ink at a 27° take-off angle.

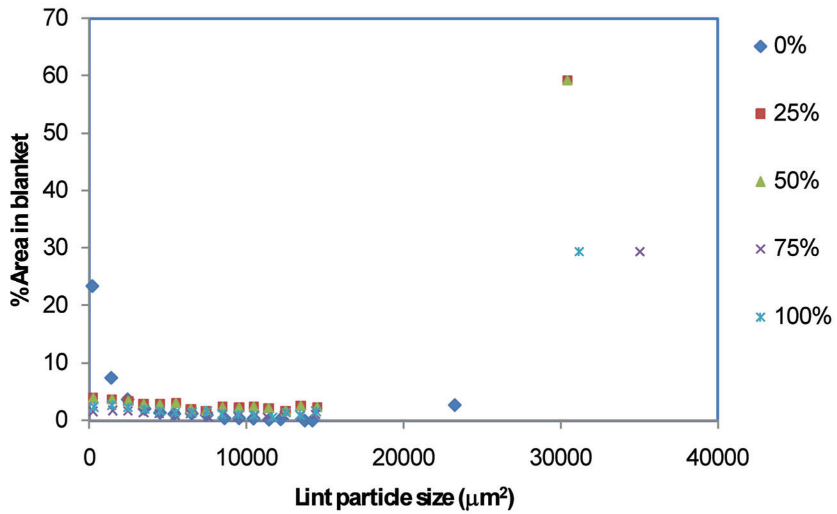

Figure 7. % area of lint particles on the blanket for printing the bottom side of the paper with tack 13.5 black ink at a 153° take-off angle.

all particles with size 15,000μm^2 and upwards are included in the last data point.

When the effect of printing tone is compared for the two take-off angles and sides, the data shows a much higher fraction of the lint area is made up of particles in the largest size class for the 153° take-off angle in comparison to the 27° take-off angle. The shift from smaller to larger lint particles with higher take-off angle is consistent with the increase in take-off angle producing higher forces on the surface, as previously discussed. However, these two figures also show no consistent trend with tone. The average size of the lint particles in the largest class shows no trend with tone and the distributions are similar with different tones. It should be noted that the 25% and 50% tone data have higher blanket areas in each size class, consistent with these tones producing the greatest overall lint, but the distributions are similar to the 75% and solid lint. Data from the measurements with the other tack inks show similar results. The data for the tack 4 inks have been published in [5].

The evidence suggests that although a higher amount of lint is produced at printing tones of 25 and 50%, the force applied to the paper surface is approximately constant. The effect of tone cannot be an area coverage effect as it would be expected that the lint would rise proportional to tone, as more of the surface is covered. This is also unlikely to be an effect of the tack force, as reducing the ink coverage should reduce the tack force applied to the surface. There is also no evidence of the additional fountain solution applied around the half tone dots weakening the paper and thus causing more lint, as has previously been proposed [22], as the residence time in a printing nip is too short to allow absorption of water and weakening of bonds. After examining possible mechanisms, we believe that the most likely mechanism explaining the trends with printing tone is spreading of the dots that make up a half tone print. Theoretical and experimental studies [28] have shown that dot-gain is a maximum for low printing tones (0–40% tone) and falls at higher printing tones, reaching, by definition, a dot gain of 0 at a solid tone of 100%. The maximum in dot gain is a consequence of the change in dot size. At a fixed screen ruling, a lower tone value implies a lower dot area. The increase in dot-gain at lower tones arises because smaller ink volumes with smaller dots provide less resistance to flow under the applied pressure and residence time in the nip. Lint produced in the nip would then primarily arise from the flow of ink across the surface driven by the pressure in the nip, a mechanism similar to the film flow force proposed by Mangin [17], although this work did not consider changes in film flow with tone and so therefore does not explicitly predict the observed trend with printing tone. It should also be noted that while the dot gain in a solid print is by definition 0, there will still be film flow in a solid print as the ink is squeezed away from the point of maximum pressure in the centre of the nip. One study found a linear correlation between dot gain and lint, under one of the set of conditions tested [8].

We can now construct a simple model with an ink film flow force, F_f, and a tack force, F_t. These forces are not additive. We need to consider lint particles of different size classes, denoted by I, with the total number of particles available for linting in each size class denoted by N_i. Only a small fraction of the sheet is removed as lint. If we have one average bond strength for all size classes, σ, then the average force required to break a bond is σA, where A is the lint particle area. An initial form for an equation for the total area of lint removed at a particular tone, h, can then be written as

$$L_h = \sum_i c_f \left(\frac{F_f}{A_i \sigma} \right)^m N_i + c_t \left(\frac{F_t}{A_i \sigma} \right)^m N_i \tag{1}$$

where c_f and c_t are constants for the ink film flow and tack forces, respectively, incorporating ink film thickness and m is a power (m = 1). The power, m, is necessary to produce changes in the distribution of particle sizes removed as lint. If m = 1 then the distribution of particle sizes is independent of the force applied.

If we assume that the applied film flow force is proportional to the dot gain, d, then from considerations of scaling, for a given printing tone we can write $d \propto P/(\mu_n V)$, where P is the printing pressure, μ_n is the ink viscosity in the nip and V is the printing velocity. The tack force is approximately linearly related to V (Figure 5) as well as being related to the viscosity of the ink under extension, μ_t. Thus equation (1) can be rewritten

$$L_h = \sum_i c'_f \left(\frac{P}{A_i \sigma \mu_n V} \right)^m N_i + c'_t \left(\frac{VG(\mu_t)}{A_i \sigma} \right)^m N_i \tag{2}$$

where c'_f and c'_t are new constants for the ink film flow and tack forces, respectively and G is some function of the extensional viscosity. This is a highly simplified model, based only on considering the effect of take-off angle and printing tone. To demonstrate the usefulness of the approach, we will now consider whether this model can qualitatively explain the effect of other printing variables on lint. The first variable that will be investigated is the effect of speed. From this model, printing speed has two counter-balancing effects towards linting. Speed reduces the residence time in the nip, reducing the dot spreading, while increasing the tack force developed as the ink film splits. The effect of speed will depend on the balance between the two forces.

Table 3 shows the data on the effect of printing speed from the third web-fed printing trial, where the lint produced while printing 12,500 and 25,000 copies an hour are compared. The data show that, for take-off angles between 78°–153°, the higher speed is associated with higher lint, with the increase in average lint over all tones, ranging from 8 to 33%. This increase is well below what would be expected from the tack force, which the printing tack experiments in Figure 5 show is likely to have doubled with a doubling

Table 3. Measured lint weight showing the effect of speed and take-off angle for two different tack inks from the second web-fed trial.

Tack 6 Tone	*Ruling*	*Take-off angle (°)*	*Paper Side*	*12500 copies/hr Lint (g/m²)*	*25000 copies/hr Lint (g/m²)*
Picture	100	102	TS	3.66	4.01
50%	100	102	TS	4.22	4.48
25%	100	102	TS	4.81	5.32
100%	150	102	TS	3.07	3.66
50%	150	102	TS	4.48	4.04
25%	150	102	TS	4.26	4.87
Picture	100	78	BS	2.15	2.70
50%	100	78	BS	1.98	2.66
25%	100	78	BS	2.18	3.25
100%	150	78	BS	2.03	1.90
50%	150	78	BS	2.23	2.54
25%	150	78	BS	1.23	2.66
Tack 4 Tone	*Ruling*	*Take-off angle (°)*	*Paper Side*	*12500 copies/hr Lint (g/m²)*	*25000 copies/hr Lint (g/m²)*
50%	100	27	TS	1.43	1.01
25%	100	27	TS	1.34	1.23
100%	150	27	TS	1.94	1.41
50%	150	27	TS	0.87	0.85
25%	150	27	TS	1.60	1.13
Picture	100	153	TS	2.06	1.50
50%	100	153	BS	3.38	4.31
25%	100	153	BS	3.69	4.48
100%	150	153	BS	3.43	4.62
50%	150	153	BS	2.56	3.82
25%	150	153	BS	4.17	5.06

of printing speed. The exception to the trend is at the lowest take-off angle of 27°, where lint decreases with speed. For this take-off angle the velocity also determines the residence time on the blanket cylinder that allows the ink to relax and spread in response to the impulse in the nip.

Two sets of experiments investigating the effect of printing pressure were conducted. In the web-fed experiment, no significant effect of pressure was found. A significant effect of printing pressure was found for the sheet-fed trials. The results are shown in Figure 8. The results show a linear increase in lint with printing pressure for both an old blanket and a new blanket. An increase in printing pressure will cause an increase in film flow and so therefore an increase in lint. This may be partially counterbalanced by the increase in the pressure forcing more ink into the pores of the surface, reducing the thickness of the ink film as it splits. However printing tack measurements conducted at different nip loadings found no difference in the measured tack force [23]. The standard sheet-fed experiment had a printing pressure of approximately 3.4 MPa.

The data also show slight differences in lint between the new blanket and the old blanket. An old blanket is more deformable than a new blanket and slippage in the nip due to deformation is believed to create additional lint [4], although there is no evidence from this data of any large effect on this press.

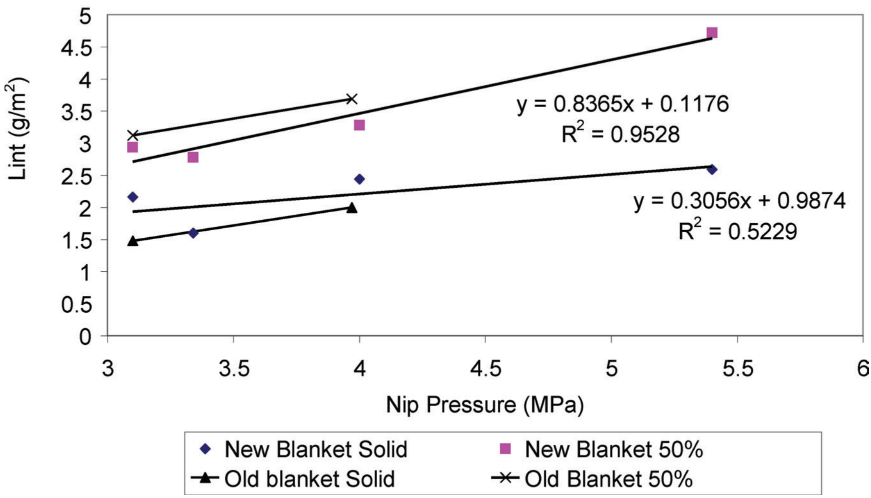

Figure 8. Effect on lint of nip pressure for the sheet-fed trials with 50% tone and solid printing.

The web-fed trials did not show a statistically significant effect of pressure. This is believed to be because pressure was changed only by swapping an old blanket for a new blanket, increasing the nip pressure and so mixing both the effect of blanket age and pressure.

Figure 9 shows the effect of ink tack on the lint after printing either with 50% or 100% screens. Results are shown for both the sheet-fed and the second web-fed trials. The web-fed results are the average of all measurements that were done at the given screen tone. This figure shows general agreement between the sheet and web-fed trials. There is very little change in the amount of lint, when the ink tack was 4, 6 or 9. However, tack 13.5 ink produced higher lint compared to the lower tack inks. Previous literature has shown [21] a trend across many, but not all, observations that lint increases with ink tack. It is worth noting that though the blanket lint showed relatively little change below tack 9, the amount of material that migrated to the plate surface increased with increasing ink tack. This had a very noticeable effect upon print quality, especially on the prints with tack 13.5 ink.

To test the reasons for this trend, we measured apparent shear viscosity against apparent shear rate for all inks, which is shown in Figure 10. All inks were shear-thinning and had a linear relationship on the log-log plot. The

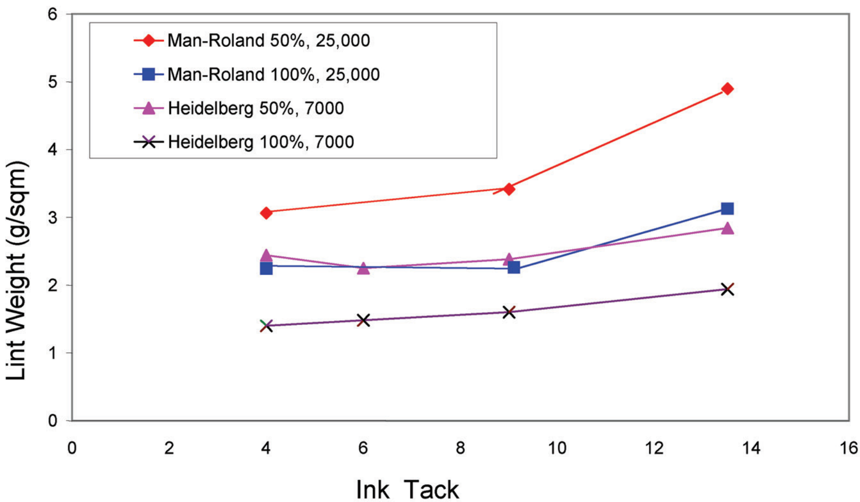

Figure 9. The effect of ink tack on lint measured in sheet-fed (Heidelberg) and web-fed (Man Roland) trials.

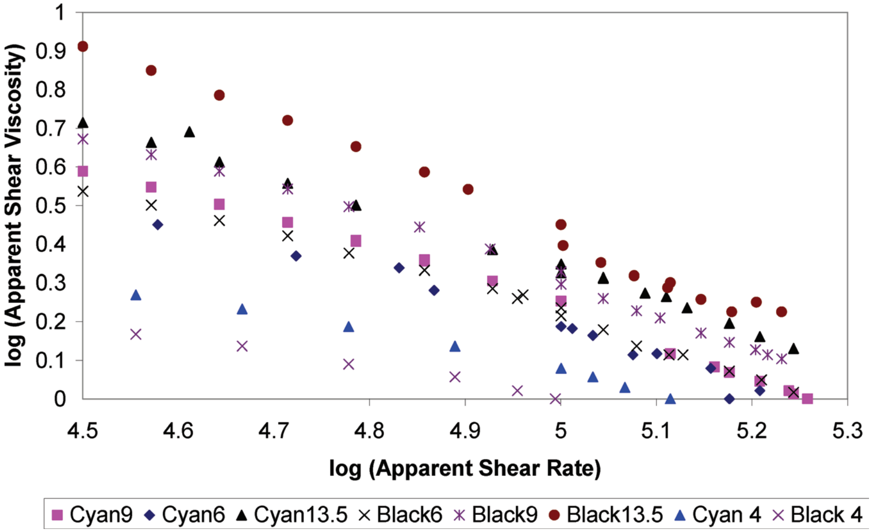

Figure 10. Apparent shear viscosity as a function of apparent shear rate for different tack inks.

data also showed a direct relationship between shear viscosity and the nominal value of ink tack reported by the manufacturer.

From equation 2, an increase in ink tack will reduce the lint from film flow, because the more viscous ink will deform more slowly in the nip. At the same time, a higher tack ink will produce a higher printing tack force. Thus the observations in the literature that lint mostly, but not always, increases with tack are explainable as sometimes the change in the film flow force dominates, whereas other times, the change in the tack force dominates.

Finally, we will discuss the effect that paper properties have on lint to examine if we can relate the properties of individual rolls of paper to their corresponding linting performance. We concluded that due to the variation in individual measurement, it was preferable to start with statistical analysis of entire data sets. Table 4 shows average lint measurements from both sheet-fed and web-fed trials. The sheet-fed data are the average of identical trials on eight and seven rolls of the improved news and newsprint A, respectively, using a black tack 13.5 ink. The web-fed trial data are the average of 4 colours X 5 screen tones X 2 take-off angles = 40 individual lint measurements for each paper. The data were analysed for statistical significance at the 95% confidence interval using a two tail T-test- i.e. the variance of the

Table 4. Average lint weights measured for the improved news and newsprint A for sheet-fed and web-fed trials. Bold values show statistically significant differences between improved news and newsprint A.

	Average Lint (g/m^2)	*50% Screen Lint (g/m^2)*	*Solid Lint (g/m^2)*
	Sheet-fed	*Sheet-fed*	*Sheet-fed*
Improved news	**2.98**	3.40	**2.57**
News A	**2.09**	2.43	**1.74**
	Web-fed 1		
Improved news	**2.62**		
News A	**1.78**		

distributions for improved news and the newsprint were not assumed to be the same.

Except for the sheet-fed 50% screen lint, the data all show statistically significant higher lint for the improved newsprint, with an average increase in lint of 45% for the improved newsprint. The differences for the sheet-fed 50% screen lint would have been statistically significant if the variances were assumed the same and a one tail T-test used.

Table 5 shows the average measurements of paper properties for each grade of paper. Numbers in bold show statistically significant differences between the improved news and the newsprint at the 5% level.

The surface strength measurements are consistent with the higher filler content of the improved newsprint. The surface strength values are 9% higher on average for newsprint A. Thus at least some of the difference can be explained by a reduction in the bond strength holding the lint particles into the surface.

The tack measurements in Table 5 are of great interest as printing tack force from the laboratory test, on average, is inversely related to lint. The difference in tack force measurement comes despite the other laboratory printing conditions being essentially constant for all samples tested. The ink weight was chosen for all samples to produce a print density of 1.0 at an interpolated test speed of 0.75 ms^{-1}. It can be seen from the table that there was no difference between the two grades for the average ink transferred to the test strip to achieve this print density.

Table 5. Average paper properties of samples of eight and seven rolls of improved newsprint and newsprint A, respectively. Bold values show statistically significant differences between improved news and newsprint A.

	Surface Strength (N/m)	*Roughness (μm)*	*Avg Pore Diameter (μm)*	*Avg Tack Force (N)*	*Avg Ink Transfer (g/m²)*
Improved news	**677.1**	**4.09**	**2.08**	**0.25**	1.11
News A	**742.9**	**3.81**	**2.58**	**0.32**	1.11
	LRC	*SRC*	*TRA*	*AFL*	
Improved news	1.99	0.39	0.43	122.7	
News A	2.10	0.43	0.48	124.7	

The other statistically significant differences between the two grades of paper are the roughness and the average pore diameter, with the improved newsprint being rougher, but with a smaller pore diameter. It is our hypothesis that these changes in surface characteristics between the two grades has caused both an increase in the film flow force as well as the reduction in the printing tack force and that overall the change is leading to higher lint for the improved newsprint. This conclusion obviously is highly speculative and a subject that needs further research.

Long Rising Component (LRC), Short Rising Component (SRC), Total Rising Area (TRA) and number of fibres measured (AFL) are all measures of fibre rising measured with the FRT1000 fibre rising tester. The small differences between these measures for the improved news and newsprint A were not shown to be statistically significant. We had been interested in the potential of the fibre rising tester to measure candidate fibres for linting. However, from these results, this hypothesis was not supported. Previous researchers [4] have also found a similar lack of correlation between results from the fibre rising tester and lint from printing trials.

CONCLUSIONS

Web-fed and sheet-fed linting trials have been used to investigate the effect of important press variables on linting. Two forces were identified as being especially important to linting, a film flow force in the nip and a tack force from the splitting of the ink film. A simple model was presented that was able to qualitatively explain trends with printing press speed, printing pressure and ink tack. An improved newsprint and a newsprint were compared for linting. The improved newsprint had statistically significant worse linting for both the sheet-fed and the web-fed trials. Part of the increased linting was attributable to the lower surface strength of the improved newsprint. The tack force measured in laboratory printing was found to be lower for improved newsprint compared to newsprint. Differences in the film flow in the nip caused by changes in roughness and porosity were suggested to be responsible for both the reduction in the tack force and the increase in linting.

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Transcription of Discussion

FUNDAMENTAL STUDIES OF LINTING IN OFFSET PRINTING OF NEWSPRINT

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Ilya Vadeiko FPInnovations

Thank you very much for a very interesting talk; I have a comment and a question. In the beginning of your presentation, you mentioned that it is difficult to measure the length in a laboratory environment because we need to print a lot of paper. The comment is that, at FPInnovations, we have a linting and piling tester that tests large paper webs at high speeds.

The question is that you did not seem to differentiate a lot between image and non-image area linting but paper faces different liquids in different areas – fountain solution in the non-image area, and ink in the image area. So when you discussed the tack force, it may be relevant for ink in one respect and for fountain solution in another. The question is: when you did the test, what were your print patterns? Were they just a range of halftones – e.g. 0 halftone ranging to 100 halftones – or did you have areas of purely non-image area type and purely solid? You do not really mention what kind of lint you are referring to.

Warren Batchelor

We had enough space on our blankets to have dedicated areas – image and non-image blocks – which had enough space to collect lint for weighing by tape pull as well as to collect the lint particles by washing for image analysis. These were all separate and they were all running at the same time.

Discussion

Ilya Vadeiko

But when you showed these results, for instance, for the effect of contact angle or tack force, is it an average over all the areas that you had printed or some specific type of area?

Warren Batchelor

Typically when I am taking those, it is an average over everything. So I have included the solid, 75, 50, 25 and non-image area as well.

Ilya Vadeiko

So my question then is, do you think the factors that you discussed, like contact angle or tack force, have the same effect on image and non-image areas, and on the areas where paper faces fountain solution and ink?

Warren Batchelor

Well clearly not for tack force and I suppose, strictly speaking, I should have excluded the non-image area data from these averages. The trends indicated that splitting rates still had significant impact, even on the non-image area. It is hard to define the tack of a water film, but there must still be some effects, or perhaps scuffing, in what happens when the splitting rate increases.

Ilya Vadeiko

But what would be your thoughts on the take-off angle? What is the effect of the take-off angle in the non-image area and image area, is it the same?

Warren Batchelor

The non-image area lint also increases at high take-off angles, but I would need to actually go back to the data to confirm the magnitude of the effect.

Ilya Vadeiko

Okay, thank you.

Graham O'Neill Imerys Minerals

There is a very simple linting test actually that correlates well with commercial printing, where you just pass samples through a dry nip between a printing blanket and a dry roller. You just measure the optical density before and after and it is very simple, it correlates very well and you can also take sellotape pulls off the areas on the blanket where the lint builds up and look at what is coming off as lint. In terms of minerals you get a very good correlation with a 2 µm content in the linting and, as you go finer, the linting drops off quite dramatically. Also between "coarse" and "blocky" and "platy", as you go towards "platy" the linting also drops off. When we did a lot of work on this several years ago, we saw a big difference between the printed and non-printed area and it seemed very much as if the mineral was collecting in the non-printed areas and the fibre was collecting in the printed areas.

Wolfgang Bauer Graz University of Technology

I think the first image that we saw showed the sun and you showed the area on the blanket around the sun. By my definition, that would be build-up and not linting.

Warren Batchelor

Well, it is what we would call sand-dune linting, where the small lint particles actually move around the blanket and tend to accumulate in wavy lines. This may contain some mineral fillers, as you suggest. The tape-pull measurements measure all solid material transferred from paper to blanket, irrespective of whether they are from fibres or filler.