OFFSET PRINTING BEHAVIOR OF BAGASSE AND HARDWOOD PAPER SHEETS LOADED BY IN-SITU PRECIPITATION

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Standard handsheets of bleached bagasse and hardwood pulps were prepared with calcium carbonate filler loading by conventional method and by in-situ precipitation. The handsheets were printed with an IGT printability tester. The effect of filler loading by in-situ precipitation on ink transfer, print density, and print-through was studied. For a given amount of ink on the printing disk or on the paper, the print density was greater and the print-through was less for in-situ precipitation of filler when compared with the conventional filler loading.

Keywords: Filler loading; In-situ precipitation; Bagasse pulp; Ink-transfer; Print density; Print-through

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INTRODUCTION

Fillers are used in paper to improve many structural, optical, and printing properties. The filler can be incorporated in a paper sheet by two different procedures: conventional loading and fiber loading. In conventional loading, the filler particles are added directly into the stock, and in fiber loading, filler particles are placed within the fiber lumen or cell wall either by mechanical diffusion or by in-situ precipitation.

Methods for incorporating fillers inside fiber lumen have been studied extensively. Green et al. (1982) and Middleton and Scallan (1985) studied loading of fiber lumens with titanium dioxide particles by mechanical diffusion, in which the slurry consisting of softwood fibers and titanium dioxide was stirred over a period of time. Middleton and Scallan (1989) also suggested use of a polymeric retention aid to enhance the retention of filler particles in the fiber lumen. Many other investigators followed a similar approach using precipitated calcium carbonate (PCC) in place of titanium dioxide (Middleton et al. 2003; Miller and Paliwal 1985; Petlicki and van de Ven 1994). The lumen loading was found to result in paper sheets having better formation and strength properties than the conventionally loaded sheets at equal filler levels.

Allan *et al*. (1992a) pointed out that the technique of lumen loading by mechanical diffusion, although theoretically promising, was limited to rounded pigment particles having size small enough to pass through the pit apertures of the fibers. They suggested that the filler particles could be incorporated within the cell wall voids (as high as 1.5 mL/g of pulp) by in-situ precipitation of insoluble inorganic materials. The concept of fiber or cell wall loading by in-situ precipitation has attracted attention of many researchers (Craig 1952; Allan *et al*. 1992a, 1992b, 1998; Yoshida *et al*. 1987; Klungness et al. 1996, 2000; Siven and Manner 2003; Subramanian et al. 2005, 2007; Chauhan et al.

2007; Kumar et al. 2009). In these techniques, an insoluble salt, which acts as filler, is precipitated within the micro voids of the cell wall or in the lumen of the fiber.

In the conventional loading procedure problems associated with fines retention and weakening of the paper sheet assume increasing importance at high filler levels. The retention of fine mineral particles is reduced, resulting in white waters with high solids content. The chemicals used to aid the retention of fillers also cause flocculation and agglomeration of filler particles and pulp fines, thereby tending to impair the paper formation, which often limits the effective use of retention aids. Thus, retention is normally compromised with the quality of the formation of the sheet. Very fine filler particles added directly to the stock interfere with the fiber bonding and result in lower sheet strength.

Loading of filler in the fiber lumen or cell wall may offer new avenues to improve retention without affecting the formation adversely, since filler retention in this case would not depend on may be decreasingly dependent on retention chemicals, flocculation, and agglomeration. Further, this type of loading may be utilized to modify certain fiber characteristics, such as its flexibility, and consequently the sheet properties. Several advantages of putting filler inside the fiber over conventional filler loading have been suggested (Allan 1995).

There is no unanimity among the researchers on the effect of fiber loading on optical properties of the resulting paper. Klungness et al. (1996, 1999, and 2000) found that the brightness and whiteness of pulp loaded by in-situ precipitation of calcium carbonate was less than that of the conventionally loaded pulp. Subramanian et al. (2005) from the study of blend of pulp and PCC composite fillers observed that adding PCC composite filler to the furnish enhanced light scattering properties of paper along with the tensile strength and Scott bond strength when compared with the conventional addition of PCC. Siven and Manner (2003) observed a decrease in both opacity and scattering coefficient on fiber loading of a mechanical pulp (pressurized groundwood) by in-situ precipitation of an aluminum compound. Chauhan et al. (2007) did not find any significant difference in the optical properties of the papers filled by in-situ precipitation or conventional loading with sodium alumino silicate in hardwood sheets.

Allan *et al*. (1998) have shown that the *in-situ* precipitation of filer within the fiber wall could be utilized to obtain gains in optical properties of a newsprint furnish consisting of blends of semichemical soda bagasse pulp and semibleached kraft softwood pulp at equal strength levels. However, at equal filler levels, the scattering coefficient values were slightly less for the fiber-wall loaded sheets than for the conventionally loaded sheets.

In an earlier study (Kumar et al. 2009), the authors found a significant improvement in light scattering coefficient of sheets made of bagasse pulp loaded by in-situ precipitated calcium carbonate. We have extended the study to evaluate whether the improved scattering coefficient of bagasse fibers loaded by in-situ precipitation of $CaCO_3$ was also complemented by improved performance in offset printing.

EXPERIMENTAL WORK

Preparation of Handsheets

The pulps used in this study were never-dried elemental-chlorine-free (ECF), bleached bagasse and ECF, mixed hardwood (acacia and casuarina) pulps obtained from an integrated pulp and paper mill. The pulps were beaten in a PFI mill to 32 °SR and loaded by *in-situ* precipitation of calcium carbonate, as described by Kumar et al. (2008). Standard hand sheets of 60 g/m^2 were prepared from the in-situ precipitated bagasse and hardwood pulps in a laboratory sheet former with a square cross section, 165mm x 165mm, according to the standard method SCAN C: 26. The handsheets were air dried in contact with glaze plates. The handsheets were internally sized by AKD to give Cobb$_{60}$ sizing test values of about 22 g/m^2. For comparison, standard handsheets were also prepared from bagasse and hardwood pulps with direct addition of a commercial filler grade precipitated calcium carbonate (PCC) pigment and a retention aid obtained from a local chemicals supplier. The filler content of unprinted pulp sheets, as $CaCO_3$ was found by ashing at 900^{o}C and using a factor of 0.56 to account for the decomposition to calcium oxide.

Printing of Handsheets

Handsheets of bagasse and hardwood pulps, both loaded conventionally and by in-situ-precipitation, were printed with an IGT printability tester (Model AIC$_2$5). Test strips of the required length of 315 mm were prepared by butt-joining two handsheets with a thin adhesive tape at the backside. The paper strips were printed with varying amounts of ink present on the printing disk while maintaining the other printing conditions constant, as shown in Table 1.

Table 1. Printing Conditions in IGT Printability Tester

Atmospheric conditions during printing	(Temp=27±1^{o}C; RH=65% ±5%)
Printing ink	Standard black offset ink supplied by the IGT. The ink was of the non-drying, oil-based type containing carbon black as pigment.
Printing speed	1 m/s
Printing force	300 N
Printing disk	IGT Rubber covered disk, 50 mm
Backing material	None

A sufficient amount of ink was initially applied to the IGT inking unit and distributed uniformly on different rolls of the inking unit. During a test print, the printing disc was weighed, using an analytical balance with a least count of 0.1 mg, before and after the inking, and again after the printing. From these weights it was possible to determine the amount of ink present on the printing disc before the printing and the amount of ink transferred to the paper during the printing.

The printing disc was cleaned after printing each strip using a solvent (cyclohexane). No fresh ink was applied to the inking unit after the initial application. This ensured that the amount of ink applied to the printing disk gradually decreased with printing of each strip. For each type of paper sheets, a series of strips was printed with varying amounts of ink on the printing disc. The initial amount of ink applied to the inking unit was adjusted such that the printing disk received an amount of ink equivalent to about 30 g/m^2 of the disc surface in the first inking. This amount decreased gradually with continued printing of paper strips. The prints were allowed to air-dry overnight. For calculation of print density and print-through, various reflectance values on the test strips were measured using L&W Elrepho-071/070 brightness tester.

RESULTS AND DISCUSSION

The physical properties of the pulps used in the study are given in Table 2. The filler level of the handsheets used for printing was in the vicinity of 15%. The actual percentages of ash present in the sheets are given in Table 3.

Table 2. Physical Properties of the Pulps Used

Property*	Bagasse	Hardwood
Ash, %	0.61	0.66
Tensile index, Nm/g	58.90	65.60
Tear index, mNm^2/g	3.96	5.34
Folding endurance	1.39	1.47
Brightness, %	73.50	73.00
Scattering coefficient, m^2/kg	21.20	36.73
Absorption coefficient, m^2/kg	0.52	0.73

Table 3. Percentage Ash in the Sheets used for Printing

Particular	Bagasse		Hardwood	
	Ash %	Sp. scattering coeff. (m^2kg)	Ash %	Sp. scattering coeff. (m^2kg)
No filler addition	0.61	21.20	0.66	36.73
Loading by In-situ precipitation	15.67	53.64	13.88	53.91
Direct loading	14.41	28.92	13.17	40.94

Ink-Transfer

Figure 1 shows the amount of ink transferred to the paper, y (g/m^2), as a function of the amount of ink present on the printing disc, x (g/m^2), for the handsheets made of bagasse and hardwood pulps. The curves represent the typical ink transfer behavior for uncoated papers (Walker 1981). For a given value of x, the amount of ink transferred to the paper was more for loaded papers than for unloaded papers in case of both bagasse and hardwood pulps. Among the loaded papers, the ink transfer was more for direct loaded papers than for papers loaded by in-situ precipitation. The possible reason for this behavior may be the positioning of the filler particles in the inter-fiber voids in direct loaded sheets, thereby, increasing the surface smoothness and the fineness of the surface pores. On the other hand, in-situ precipitation, the filler particles are present mainly inside the fiber structure, from where they have little influence on the roughness and porous structure of the paper surface (Kumar et al. 2009).

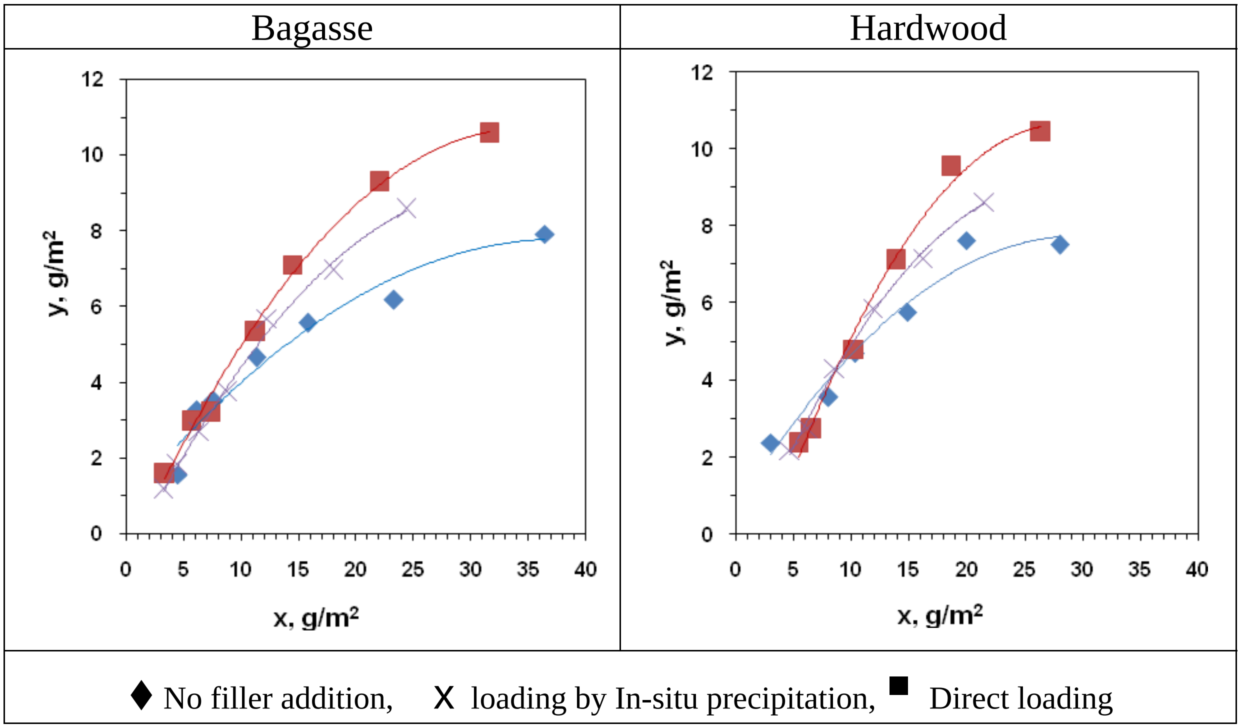

Fig.1. Amount of ink-transferred, y, as a function of the amount of ink on the printing disc, x.

The parameters of the Fetsko-Walker ink transfer equation were determined for each type of sheets by fitting the experimental (x, y) data to Eqs. 1 and 2, following the technique described by Singh and Garg (2005). Initial values of b and f were determined by a linear regression of the experimental x and y data for large values of x (Eq. 1), and then the final values of b, f, and k were determined from Eq. 2 by using a direct search technique in the vicinity of the initial values of b and f. The data gave an excellent fit to Eq. 2 as represented by very high values of correlation coefficients. The 95% confidence interval of the population correlation coefficient was determined using Fisher's Z transformation (Murray and Larry 1999) method and assuming (x, y) data to have a bivariate normal distribution. The values of ink-transfer parameters of both bagasse and hardwood handsheets and the correlation coefficients in each case are given in Table 4. For the handsheets studied, the values of b and k were nearly the same for bagasse as well as hardwood, and unfilled as well as filled handsheets. However, the values of f were lower for bagasse pulp than for hardwood pulp. For a given pulp type, the f values increased with loading the sheets with filler, the increase being slightly more in directly loaded sheets than in-situ precipitated sheets.

$$y = b + f\,(x-b) \tag{1}$$

$$y = (1-e^{-kx})\,[b\,(1-e^{-x/b})\,(1-f) + f\,x] \tag{2}$$

where
y = amount of ink transferred to the paper per unit area, g/m^2
b = amount of ink immobilized by the paper surface, g/m^2
x = amount of ink originally present on the printing disc, g/m^2
f = ink split factor representing the fraction of free ink, (x-b), between the disk and the paper surface, transferred to the paper.
k = a constant dependent on the smoothness of paper
r = correlation coefficient for Eq.2
ρ_l & ρ_h = 95% confidence interval of population correlation coefficient

Table 4. Ink–Transfer Parameters

Sample	By solving Eq. 1		By solving Eq. 2					
	b	*f*	*b*	*f*	*k*	*r*	ρ_l	ρ_h
Hardwood								
No filler loading	4.08	0.16	4.19	0.16	0.33	0.95	0.62	0.99
In-situ precipitation	3.57	0.29	3.26	0.31	0.23	0.99	0.95	0.99
Direct loading	3.22	0.34	3.33	0.35	0.21	0.98	0.81	0.99
Bagasse								
No filler loading	3.87	0.12	4.10	0.12	0.25	0.99	0.93	0.99
In-situ precipitation	3.58	0.24	3.77	0.25	0.18	0.99	0.98	0.99
Direct loading	4.22	0.25	3.40	0.28	0.32	0.99	0.90	0.99

Print Density

Print density is the optical contrast between the printed and unprinted areas on the paper surface. This contrast is usually determined from the measurement of reflectance values of printed and unprinted areas (SCAN P-36) as:

$$PD = \log (R_\infty / R_P) \quad (3)$$

where
PD = print density
R_∞ = reflectance of unprinted paper on the print side backed with an opaque pad of the same paper,
R_P = reflectance of the printed paper backed with an opaque pad of the unprinted paper.

The reflectance measurements were made on an L&W Elrepho-074 instrument corresponding to ISO Y-C/2°. An average of five measurements was recorded for each printed strip.

Figure 2 shows the variation of print density with varying values of x and y for both the bagasse and the hardwood handsheets. An observation of the figures revealed the following points:

1. For any given ink transferred to the paper, the print density was greater for bagasse sheets than for the hardwood sheets, particularly for large values of y.

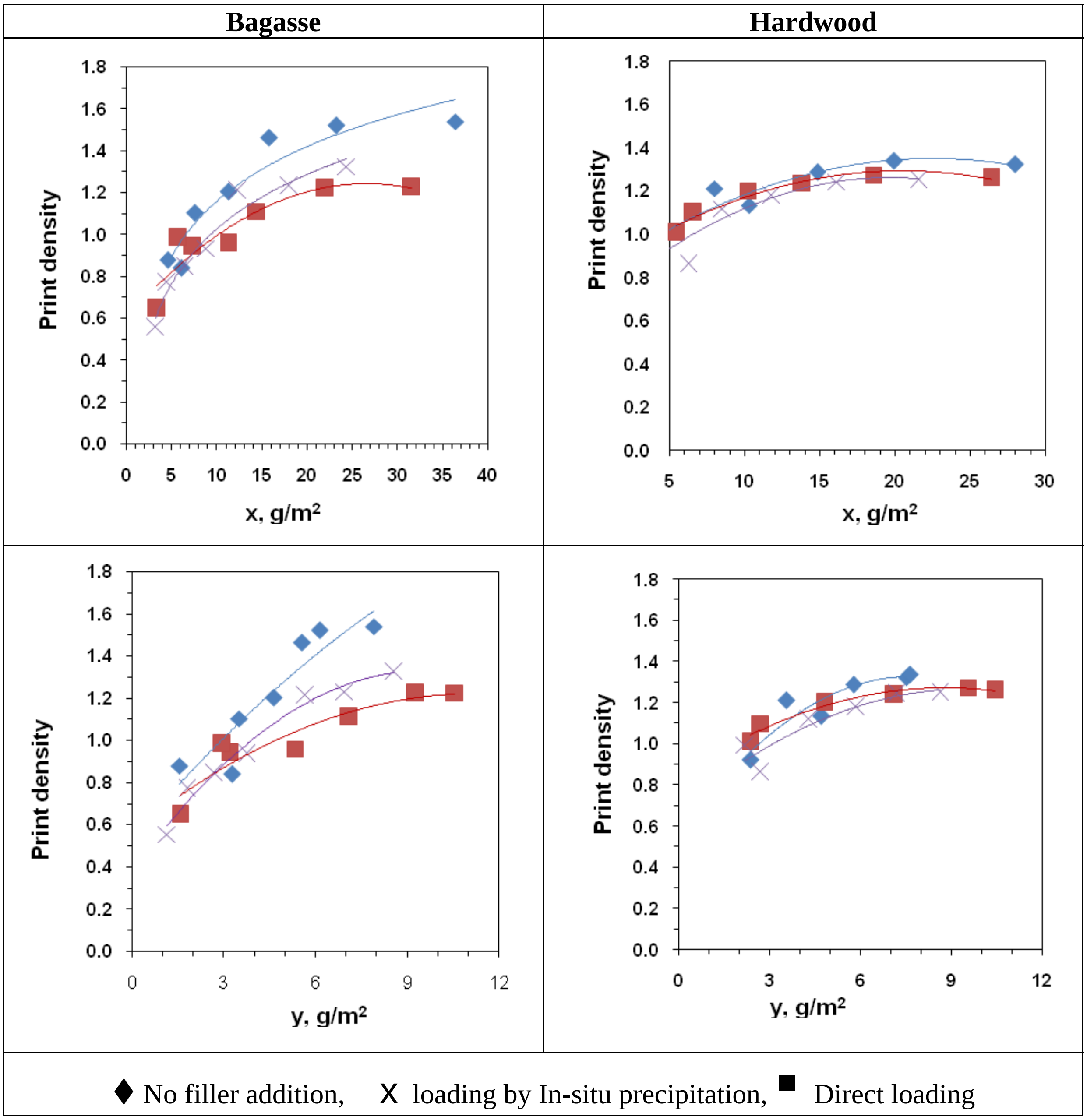

Fig. 2. Print density as a function of amount of ink on the printing disc and the amount of ink transferred to the paper

2. For hardwood pulp, the print density at given amount of ink transferred to the paper was nearly the same for unfilled sheets as well as for loaded sheets, either by direct loading or by in-situ precipitation.
3. For bagasse pulp, the print density at given amount of ink transfer was different for unloaded and loaded sheets. The print density was lower for the loaded sheets than for the unloaded sheets. Further, the print density was more for the sheets loaded by in-situ precipitation than the sheets loaded directly.
4. Even though the ink transferred to the loaded bagasse sheets was more than that for the unloaded sheets, they had lower values of print density. The reflectance of the printed areas (R_P) was greater in these cases due to considerably higher values of scattering coefficient of the paper sheet beneath the ink layer.

Print-Through

Print-through is an undesirable phenomenon in printing, in which the print is visible from the reverse side of the printed paper. It is defined as the contrast between the printed and the unprinted areas when viewed from the reverse side of a print (SCAN P-36):

$$PT = \log\left(\frac{R_{\infty B}}{R_{pB}}\right) \quad (4)$$

where,

PT = print-through,
$R_{\infty B}$ = reflectance of unprinted paper on the reverse side backed with an opaque pad of the same paper,
R_{PB} = reflectance of the printed paper on the reverse side backed with an opaque pad of the unprinted paper.

Figure 3 shows the variation of print-through values for bagasse and hardwood sheets as function of x and y. For hardwood pulp, the print-through decreased with loading of filler, but with little difference in the manner of filler loading, whether direct loading or loading by in-situ precipitation. On the other hand, for bagasse sheets, the effect of filler addition in reducing the print-through was very significant, and more so for the loading by in-situ precipitation.

By increasing the amount of ink on the disk or the paper, a desirable improvement in print density is obtained along with the undesirable increase in the print-through. Figure 4 shows the print-through as a function of print density for bagasse and hardwood sheets. It was observed that for a given print density, the bagasse sheets loaded by in-situ precipitation had nearly the same values of print-through as the hardwood sheets at equal filler level. This reduction in print-through for bagasse sheets was largely because of the very significant improvement in scattering coefficient of the pulp on filler loading by in-situ precipitation (Table 3).

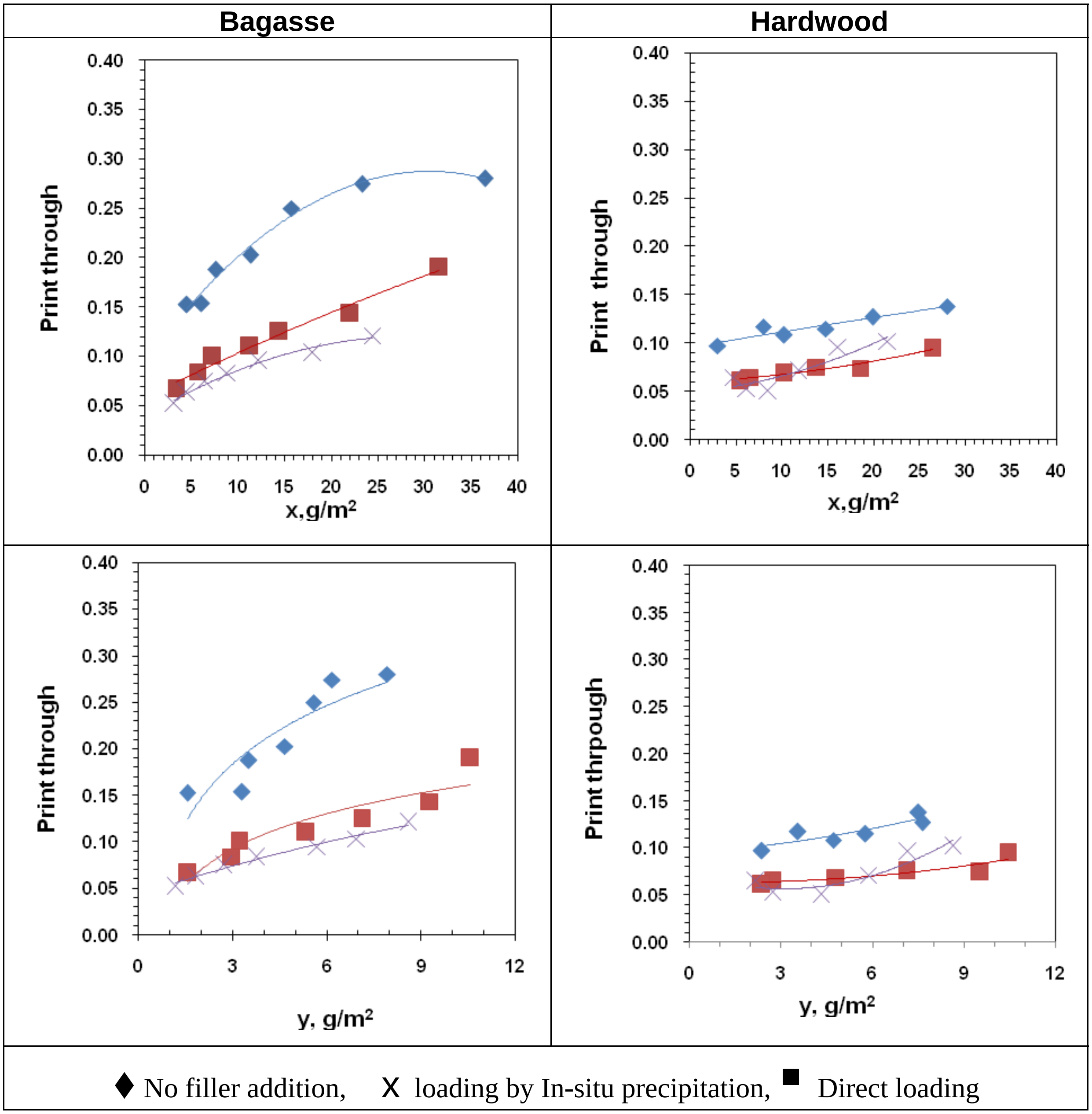

Fig. 3. Print-through as a function of amount of ink on the printing disc and the amount of ink transferred to the paper

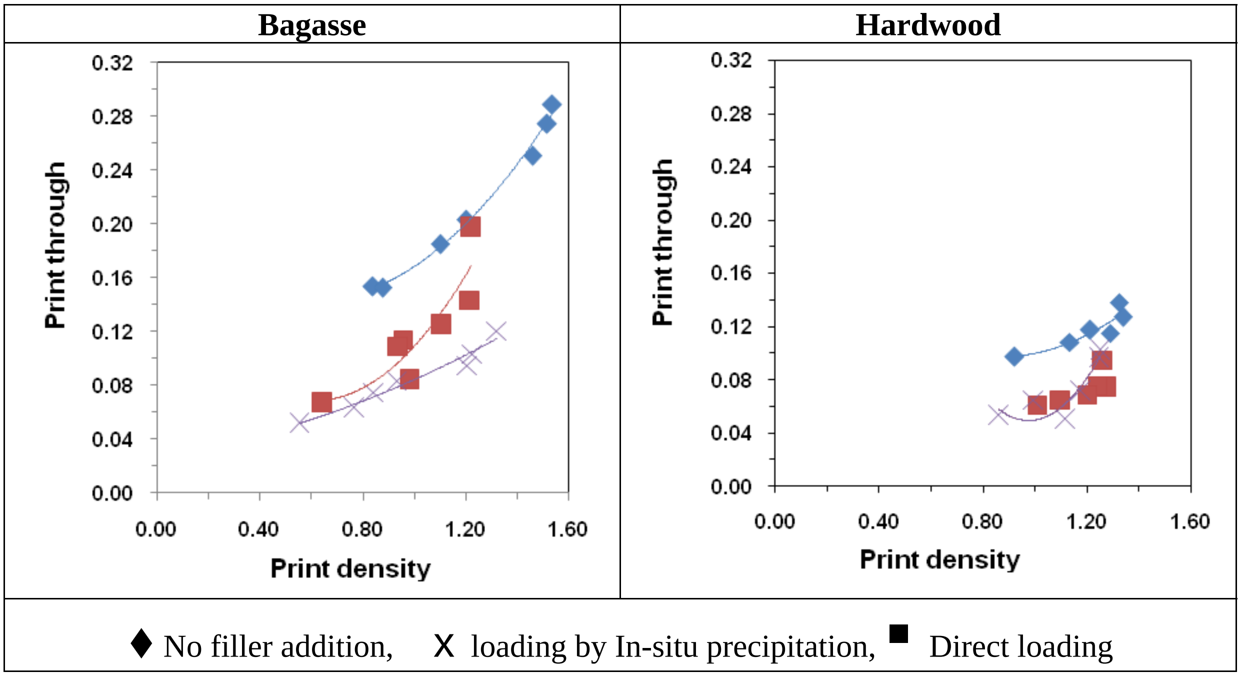

Fig. 4. Print-through as a function of print density

CONCLUSIONS

1. For a given amount of ink on the printing disc, the ink transferred to paper sheet increased on loading of the paper with filler. The ink transfer was more for directly loaded papers than for papers loaded by in-situ precipitation. This difference in ink transfer behavior could be due to differences in the positioning of the filler particles. The filler particles are present in the inter-fiber voids in direct loaded sheets, but mainly inside the fiber structure in sheets loaded by in-situ precipitation. Filler particles positioned in inter-fiber voids increase surface smoothness and fineness of the porous structure, while the filler particles present inside the fiber have little influence on these properties.
2. When compared to direct loading, in-situ precipitation of filler in bagasse fiber showed favorable effects on both the print density and the print-through. For a given amount of ink on the printing disk or the paper, the print density was more and the print-through was less for in-situ precipitation than with the direct filler loading.
3. The observed behavior on printability parameters is largely due to a significant improvement in light scattering coefficient of the bagasse pulp on loading by in-situ precipitation of calcium carbonate in the fibers (Kumar et al. 2009). Due to the increase in light scattering, both the print density and print-through values decreased, but the reduction in the print-through was more pronounced than the reduction in the print density. For a given print density, the print-through for in-situ precipitated sheets was less than that for the direct loaded sheets and much less than that for the unloaded sheets.

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