A study on the factors affecting ink-substrate interactions in maplitho papers

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Abstract

The nature of paper used plays a pivotal role in determining the quality of the final printed product. The quality of paper is defined by a number of parameters, which affect not just the quality of print, but also controls the physical aspects during print production in offset lithographic presses. Maplitho paper is almost always the substrate of choice for run-of-the-mill commercial jobs. This work deals with the study of the inter-dependability of the various substrate parameters with the print quality. The study was conducted on commercially available maplitho papers of different GSM from various manufacturers. This work presents a relationship that exists between physical factors of the substrate like rate of penetration of ink in paper, surface regularity with ink film drying time and gloss levels of printed substrate that defines ink-substrate interactions. A strong correlation was obtained between the datasets used for the experiment suggesting that, for the same ink film, its drying time and gloss levels on different maplitho papers is dependent on physical factors intrinsic to the paper.

Introduction

Offset lithography has been a cornerstone in technology innovation for the past few centuries. It makes use of the fact that two surfaces on the same plane when treated in a particular way will have affinity towards two distinct materials, in this case ink and water. This is the very essence of high speed modern offset presses that operate today. The image carrier is an aluminium plate which contains the image areas, sensitized to receive ink and the non-image areas are desensitized to accept water. Sheet-fed offset presses makes use of a sequential arrangement of printing couples each dedicated to print a specific color, usually black, cyan, magenta and yellow. The quality of the printed sheet depends on a number of factors, sometimes even external to the printing machine itself. Some of these are the materials which go into printing, viz. ink, paper, fountain solution, etc. This work deals with the nature of a specific substrate and how it affects the quality of final output and the ink-substrate interaction.

Substrates used for sheet-fed offset presses need to have specific properties making it suitable to pass through fine gaps of rollers moving at high speed while transferring ink of viscosities of a few hundred poise. This means that the paper should have high internal bonding strength and a smooth surface. The grains or fibres of the paper should not get separated under stress and tension of the printing couple, especially when it gets pulled from one printing unit to the other. It should also possess a strong dimensional stability and remain almost inert so as to prevent any reaction between materials during print production. Most run-of-the-mill commercial jobs in the printing processes today use maplitho papers which usually lack a coating, however have a surface sized property [1]. They are also characterized by high ink absorbency rates. A number of maplitho papers were obtained from various sources. The papers having different GSM, used for testing were from multiple manufacturers and from different geographical locations of the country to obtain a wide gamut result.

Depending on the method, paper can either be acidic or alkaline. For instance, in chemical pulping [2 – 5] (sulphate process), the pulp is cooked with wood chips and sodium hydroxide and a digester (sodium sulphide). Oxygen, ozone, hydrogen peroxide, per-acetic acid, etc are used to attack the lignin [6] and converts it into compounds which are more soluble in alkali. As the organic acids are liberated from cooking the wood, the pulp turns acidic in nature which initially was alkaline. However, the process can be enacted using these components in different dosage and combination, effectively utilizing the entire pH range, making the output acidic, neutral or alkaline depending on the requirement. Another prime cause leading to the acidity of the paper is the introduction of internal sizing elements. They help in increasing the contact angle of the cellulose fibres. Alum-rosin [7 – 8] is often used for this purpose which increases acidity of the paper.

As a general rule, an increasing pH value helps in better solubility of wood pulp and also extends the amount of dissolved anions and colloids, on the other hand precipitation occur at lower pH values during pulping processes. Synthetic sizes, like stearic anhydride and alkenyl succinic anhydride are used at low pH values to react with cellulose to form an ester [9].

It is vital, that the ink applied on the substrate dries quickly at the surface so that consequent sheets do not stick to each other causing set-off problems. Drying of the ink film is dependent on various factors, one of which is being discussed in this work. The pH and rate of absorbency of the paper highly affects the ink-film drying time on the substrate. pH values for paper and paperboards ranges from 3.8 to 10.5. Uncoated papers which are machine made have a pH range between 5 and 7 while for coated paper it is 8 to 10 (due to the presence of clay and casein glue). On lowering pH, the rate of deterioration of the paper increases under humid conditions. This is because acid and aluminium ions present in the paper rapidly depolymerise cellulose molecules [10] which consequently lose their strength. As conventional oil based lithographic inks dry through oxidative polymerization [11], the acidity of the paper plays a great role during this drying phase. For papers having higher acidity, and during conditions of elevated relative humidity, the drying agents in the ink [12] get reduced to the corresponding acid and a metal is precipitated. This retards the process of ink film drying on the substrate, especially on those which are uncoated (for instance in this case mapltiho) and the base stock is in direct contact with the ink.

A number of previous works related to the rate of penetration of offset and other inks have been studied, all of which shows some correlation between the former and the drying or setting tendencies of the ink on paper. Resch et al. [13] in their study examined the role of calendaring on the pore structure of papers and its effect on optical and physical properties of the ink on paper. Rousu et al. [14] in their work has suggested that latex-oil diffusion has an important effect on the optical properties of ink printed on such papers. Studies have also been done on the absorption mechanisms of coatings and how they affect ink adhesion, mechanisms were developed to enhance capillary forces to increase absorption on oil in paper [15]. Extensive studies depict the nature of spread and penetration behaviour of fluids in paper and analyses shows that there exists discontinuous absorption rates which play a pivotal factor in determining the optical properties of paper printed by offset method. It has also been reported that the ink distribution or penetration is also affected by the surface regularity of the paper; they have suggested that there is a strong correlation between the penetrated ink and the gloss of the printed substrate [16].

Surface properties of paper like roughness, absorbency has a direct impact on the optical properties of the printed sheets. It has been seen that absorbency of inks in paper affects the colorimetric data and print density [17]. Both the above mentioned factors are pivotal in deciding the final output, as Borchers et al. [18] reported that substrate gloss affects the gloss of printed sheets more than ink absorbency. Fetsko and Zettlemoyer [19] in their study found that with higher ink absorbency rates, the gloss decreases. It has been suggested in previous works, that surface roughness directly affects the gloss of the printed stock; increasing roughness reduces gloss properties of the printed paper [20]. There is also an almost linear relationship between the porosity of the paper with surface smoothness and ink absorbency; absorbency increases with increasing porosity [21].

Table 1 Data for various properties of the substrates used for testing

Surface regularity ranking (1-roughest and 28-smoothest)	Gloss at 85^{o} GU	Difference in OD between 7 and 120 seconds (Rate of penetration)	Average drying time for CMYK process colors
1	3.55	0.05	21.25
2	3.55	0.19	22.5
3	4.3	0.23	25
4	4.3	0.30	26.25
5	4.4	0.35	27.5
6	4.55	0.37	28.75
7	4.7	0.38	30
8	4.85	0.38	31.25
9	4.9	0.39	33.75
10	5	0.41	35
11	5.05	0.44	36.25
12	5.15	0.46	40
13	5.45	0.51	42.5
14	5.45	0.55	42.5
15	5.5	0.56	43.75
16	5.5	0.57	45
17	5.75	0.57	48.75
18	5.95	0.57	50
19	6	0.58	50
20	6	0.59	53.75
21	6.6	0.64	55
22	6.7	0.65	56.25
23	6.95	0.70	58.75
24	7	0.72	62.5
25	7.05	0.73	65
26	7.8	0.74	76.25
27	10.2	0.74	82.5
28	10.5	0.74	88.75

The paper has been divided into four sections, which includes some discussions on related work done in this field, secondly, some discussions on the background of the work and mathematical foundations of the same. The third part comprises data collection and preparation and the fourth part contains the analysis of the collected data which finally culminates into some concluding remarks with scope for future work.

leading to the fact that besides oxidative-polymerization, penetration plays an important role in determining the ink film drying properties for a particular substrate. This penetration is facilitated through the availability of pores within the fibres present in the paper. The rate at which the fibres absorb a liquid (in this case, oil) is generally slower compared to the rate of absorption by the pores [24]. Previous works have dealt with

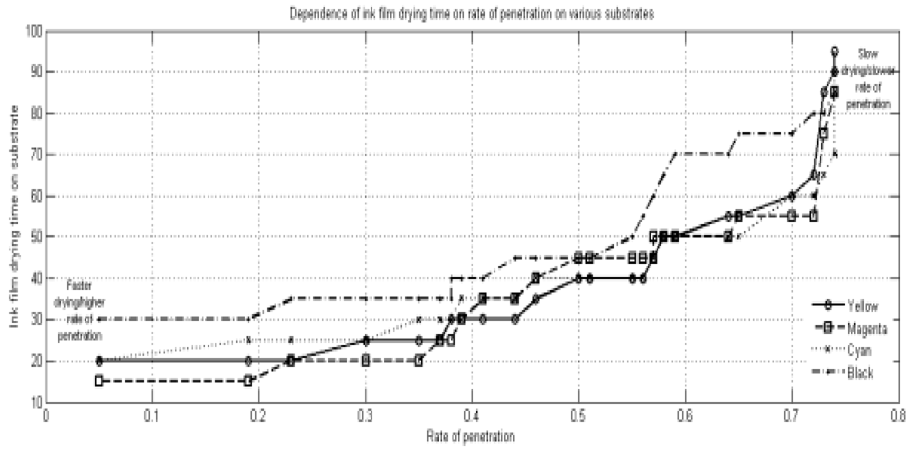


Figure 1: Dependence of drying time with rate of penetration

Theoretical background

As mentioned earlier that sizing plays an important role in determining the intrinsic properties of the paper. pH is a measure for the acidity or alkalinity, it is expressed as the negative logarithm of concentration of hydrogen ions in moles per litre. Each unit decrease in pH below 7 means a ten times increase in the acidity value [22]. As has been stated previously, there exists a strong correlation between the pH of the substrate with the drying time of an ink film on it. The pH of the paper has pronounced on the ink drying time especially under higher relative humidity conditions [23]. It is recommended that for uncoated papers, its pH should lie between 5 and 7. However, several factors determine the acidity of the paper, one of which is the use of rosin size. Rosin size is a suspension of rosin in sodium rosinate solution, which when reacts with strong acids precipitate to rosin. This is a weak insoluble acid that reacts with aluminium ion to form an insoluble compound of aluminium and rosin, effectively decreasing the aluminium ion concentration.

Maplitho papers do not usually possess internal sizing and hence enables the vehicle of oil based inks to penetrate through them, modeling the depth of penetration using microscopic images and topological analysis of the substrate with parameters including viscosity, nip pressure, capillarity [25]. Presence of pores leads to capillary forces which drives the penetration process. For a liquid to wet a surface with a finite contact angle θ, a cosine factor of the surface tension must be included, which leads to the Laplaces' equation as follows,

$$\Delta P = \frac{2\gamma_{LG} \cos\theta}{r} \qquad (1)$$

Where, ΔP is the difference between the pressure of the liquid and surrounding pressure, γ_LGis the surface energy and r is the radius. Considering viscosity of the ink and hence combining Laplaces' equation and Poiseuille's equation leading to Lucas-Washburn equation as follows,

$$l^2 = \frac{\gamma_{LG} r t \cos\theta}{2\eta} \pm \frac{r^2 d g}{8\eta} \qquad (2)$$

Where, V is the volume of the liquid, ηis the viscosity, t is the time flowing through the capillary of length l and radius r. Also d is the

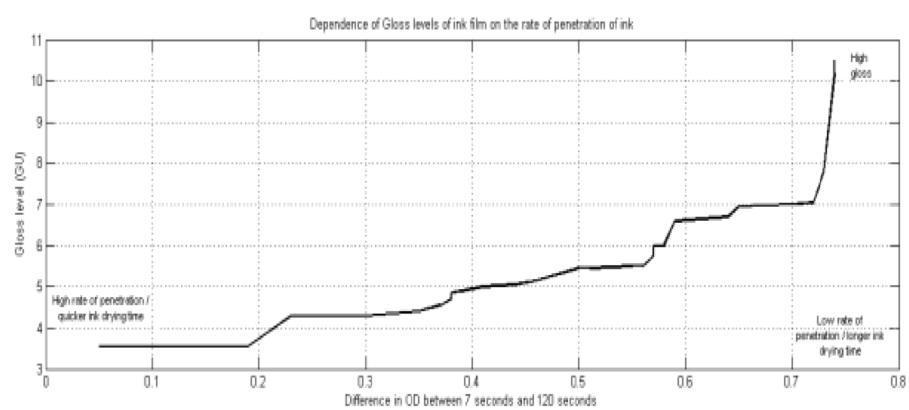


Figure 2: Dependence of gloss levels with rate of penetration

density and g is the acceleration due to gravity. On differentiating two sides with respect to t,

$$\frac{dl}{dt} = \frac{\gamma_{LG} r cos\theta}{4\eta l} \quad (3)$$

Where, $\frac{dl}{dt}$ is the rate of penetration due to capillarity.

The experiment was set up in a precise and controlled laboratory environment. The maplitho papers were collected from various sources obtained from throughout the country, a total of 28 varieties of paper of varying GSM were used for this purpose. A number of parameters related to the substrate were evaluated, first being, the rate of absorbency of ink on paper. Maplitho papers are usually porous in nature and hence penetration of ink is a determining factor in ink drying. During the printing operation, when the paper passes through the nip pressure of the rollers, the minute openings on the paper surface are constricted [26] and hence the oil based ink stays mostly on the surface. However, on release, the pores widen and allow the oil of the ink to penetrate through the paper. If however, the rate of penetration of a particular substrate is high enough then the gloss of the ink is substantially reduced giving it a fade out appearance. A quantitative evaluation of the penetration of ink on paper has been suggested in the Walker-Fetsko transfer equation [27].

$$y = b + f(x - b) \quad (4)$$

Where, b is the ink immobilization constant, and f is the ink splitting constant, y is amount of ink transferred and x is the amount of ink on plate.

Figure 3: Dependence of gloss on surface regularity

Surface regularity plays a vital role in determining the final print characteristics on a substrate. Ideally the surface of substrate should be plane, however, quite naturally during paper production a number of deformities occur on the surface. The deviations of the surface from an ideal smooth plane can be termed as surface roughness of the paper. For maplitho papers, the surface being uncoated, the roughness is quite high. This has a direct impact on the gloss and colorimetric properties of the printed sheets. The reflecting elements from a rough surface distributed through a probabilistic distribution and can be described quantitatively through the following,

$$I = e^{[\frac{-8\pi^2 cos^2 R}{\alpha\lambda^2}]} \quad (5)$$

Which works well for moderate viewing angles, R is the angle of viewing and α is a constant.

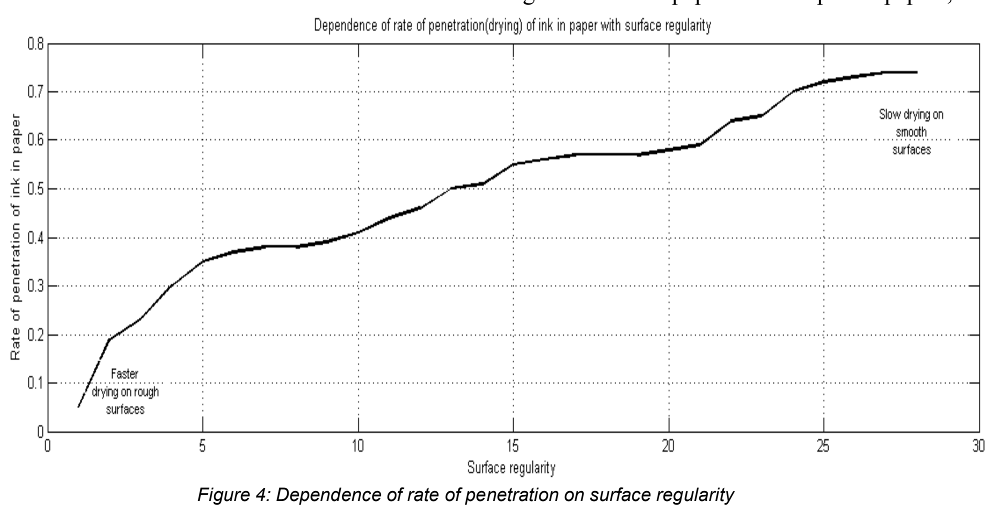


Figure 4: Dependence of rate of penetration on surface regularity

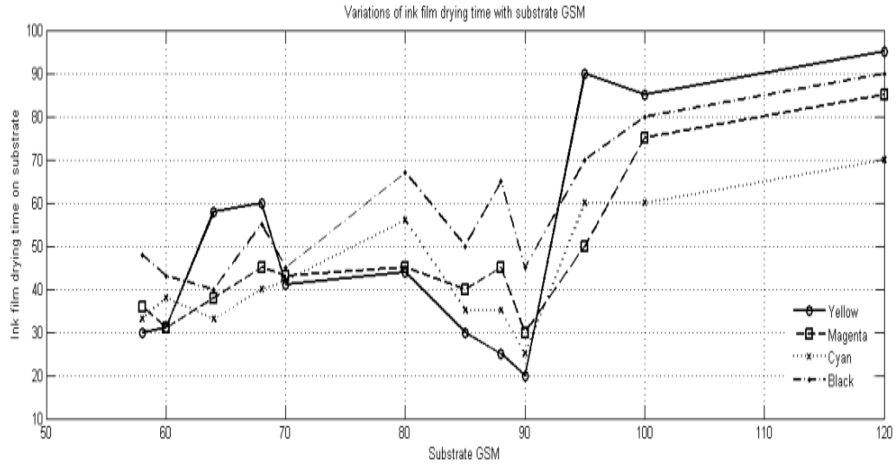


Figure 5: Variations of drying time with substrate gsm

The gloss values for a printed sheet can be measured by accounting in the specular reflection off the surface. It can be expressed by the ratio between the luminous flux reflected by the test surface in a particular angle to the same from a standard reflecting surface. This specular reflection can be expressed as [28],

$$\frac{I}{I_0} = f(n,i)e^{\left[-\left(\frac{4\pi\sigma\,\cos\,i}{\lambda}\right)^2\right]} \qquad (6)$$

Where f(n, i) s the Fresnel coefficient of specular reflection as a function of refractive index n and angle of incident light i, σ is the standard deviation of surface roughness, and λ is the wavelength of incident light.

Since surface roughness has direct impact on the gloss properties of paper, it can be safely concluded that it also has strong correlation on the colorimetric values of the printed substrates. Granzier et al., [29] has effectively shown the effect that surface properties have on the color constancy of an object, this conclusion can also be drawn to printed substrates as has been described in this work.

Data Collection

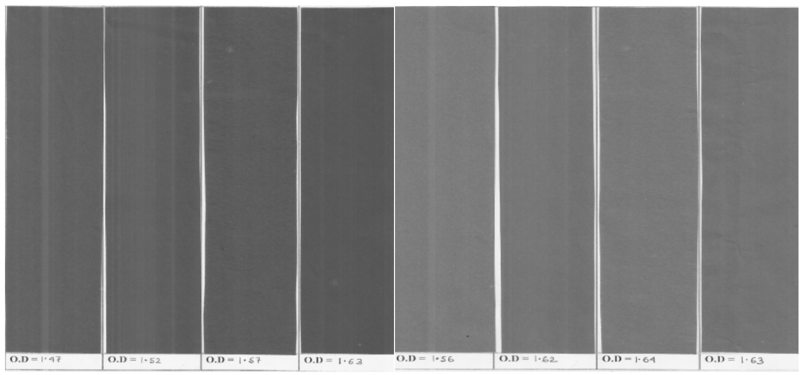
In order to estimate the rate of penetration of ink in the substrate, the Noir Porometrique 3809 ink was used and applied on the subject separately on two occasions and kept for 7 seconds and 120 seconds respectively, after which they were cleaned with cloth and distinct blots were obtained. The optical densities for the blots were measured and noted. The difference in densities between the two is the rate of penetration of ink in paper. In order to estimate surface regularity Bleu microcontour number 3811 ink was used. The paper was placed over a support substrate. Ink was applied to cover the whole paper by means of a hand roller. Then the excess ink was removed with the help of a linen cloth. The degree of colouration of the paper surface provides a fair idea on its smoothness because the test ink contains pigments having fairly large particle size, and hence upon removing the excess ink the pigment particles stick to the ragged surface of the substrate. All the substrates were checked for their surface regularity by the before-mentioned method. However, this is not a quantitative method but a qualitative one. In order to correlate the surface regularity with other physical parameters of the substrate, each of those substrates were ranked depending on their surface regularities. This was done by a panel of three visual inspectors, who viewed the substrates placed one after the other on the same plane and kept under an illumination box and ranked the substrates according to their levels of surface regularity. Their observations were then collated to obtain the final rankings of each paper. There were 28 substrates for testing, lower ranking meant rough surfaces and higher ranking meant smoother surfaces. Measurement of gloss was conducted with a TQC gloss meter at 85^0. For low gloss measurements this angle provides better visual correlation [30]. The drying tests were conducted using four process colors. A Prufbau printability tester was used to draw prints on the specific substrates and the drying time was estimated for each color and on each substrate. All the data collected has been provided in the Table 1. Some of the printed samples, roughness tests and surface absorbency tests have been provided in Figure 6.

Results and analysis

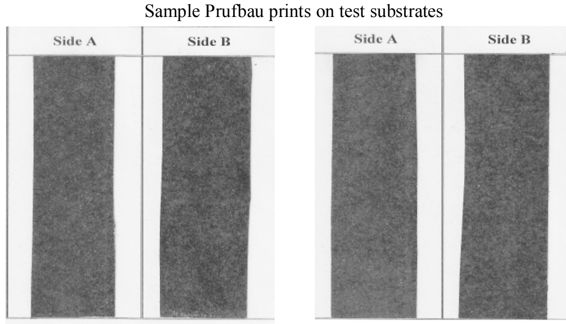
This work provides many new insights on ink film-substrate interaction. Difference in optical density (OD) of paper patches on which ink was blotted to check for surface absorbency between 7 seconds and 120 seconds served as a measure of rate of penetration of the paper. Lower differences in OD meant higher rate of penetration as it suggested that a majority of the absorption was done during the first 7 seconds. The results suggest that there exist a strong correlation between the rate of penetration of the ink in the paper and the drying time of ink film on the respective substrates. The rate of penetration is denoted by the difference in optical density of ink blots on paper between 7 seconds and 120 seconds. Lower the difference, higher is the rate of penetration. From figure 1 it can be safely concluded that with increasing rate of penetration (i.e., lower difference in OD), drying of ink on paper is accelerated almost linearly. This is true for all the process colors that were tested on the substrates. However, the drying time for black ink at low OD differences is visibly higher compared to others. Another study comprised verifying the relationship between gloss levels of ink on paper with the rate of penetration. The empirical relation suggests that with higher rate of penetration, gloss of ink decreases. Increasing rate of penetration is caused by many factors, one of which is the absorbency of the substrates, if the paper is highly absorbent then in leads to absorption of a major part of the oil in ink to leading to lower gloss levels. Figure 2 validates this very idea and shows that with increasing rates of penetration (faster drying of ink on paper), the gloss levels decreases and vice-versa. This holds true for all the process inks that were tested on the substrates. Furthermore, it was observed that gloss levels of ink also depended on the surface regularity. There was an almost linear increase in gloss levels with increasing surface regularity (i.e., smooth surfaces) and gloss levels reduced for rough surfaces, as has been shown in figure 3. Rough surfaces tend to have higher number of peaks and valley; this can affect a number of printing parameters including the nature of drying of ink films on those substrates. Figure 4 suggests that, rough surfaces leads to lower rates of penetration of ink in paper (meaning faster drying of ink on paper), and the smoother surfaces decelerates the drying time of ink film on paper. Another observation was made on the effect substrate GSM has on the drying time of ink film on paper. Figure 5 suggests that although there exists a tendency of increased drying time of ink film with increasing GSM, however, it cannot be conclusively said that it is a strictly increasing curve for any of the process inks. A sharp drop in drying time could be noticed with papers having around 90 GSM. The effect of pH on the drying properties of ink in paper are not significantly noticeable in this work because the test substrates chosen did not provide for a wide variation of pH, and as such ranged between 5.50 – 6.00.

Conclusions

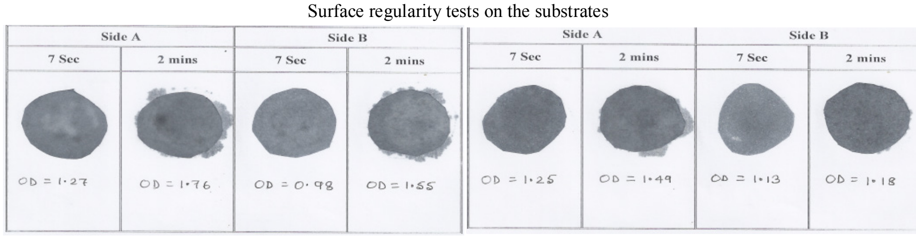
This work has been done to analyse the effect that the various parameters of paper have on the nature of printing. It has been done exclusively on maplitho paper which is used widely for lower to medium segment print finish products. Many printers often face problems arising out of poor ink-substrate interaction, while printing, but this work suggests that prior testing of certain aspects of substrate quality at manufacturer as well as the printers' end could eliminate such problems. Printing on mapltiho papers are mostly challenging due to lower GSM and surface regularity. There existed an empirical relationship between factors like surface absorbency, regularity and ink drying time, gloss levels; however, this work has quantitatively defined the actual relationship between the above-mentioned factors. The results obtained are extremely promising and has shown the effect, rate of penetration and surface regularity have on ink film drying time, gloss levels of ink on paper. The results obtained can be used for generating a quantitative threshold for the various parameters of paper that were tested, to verify if the drying time of ink and print quality on a particular paper will be in accordance to the printers' expectation. Various problems like set-off, ghosting, dot-gain can now be approximately assessed prior to printing on one of the specific papers used in this work. Further work may include microscopic evaluations of the paper surface and correlating those



Sample Prufbau prints on test substrates



Surface regularity tests on the substrates



Surface absorbency tests on the substrates

Figure 6: Samples of tests conducted on the substrates

evaluations against results obtained from this work and identifying some other factors, if any, which might have some effect on the ink-paper interactions and final print quality on the paper.

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