STUDY OF SURFACE CHARACTERISTICS OF COATED AND UNCOATED PAPER SUBSTRATES AND THEIR IMPACT ON INK DRYING ABILITY AND RUNNABILITY IN INKJET PRINT ENGINES (PIJ, TIJ)

Sandeep Boora[1] & Anjan Kumar Baral[2]

[1] Research Scholar, Department of Printing Technology,
Guru Jambheshwar University of Science Technology, Hisar City, Haryana, India
sboora1@cuh.ac.in
[2] Professor, Department of Printing Technology,
Guru Jambheshwar University of Science Technology, Hisar City, Haryana, India
anjan_baral2222@yahoo.co.in

Abstract

Inkjet printing is best suited to the short run printing jobs with additional capabilities to print variable data and personalization. The printing industry has been rapidly evolving and moving towards post-print processes that require faster ink drying times, resulting in reduced product release time. The surface characteristics of the paper have a significant impact on runnability and final printing quality. Runnability is an important aspect of the substrate which influences the consistency in print and economies of the press. This study aims to investigate the influence of different paper substrate surface properties on ink drying ability and runnability in inkjet printing machines. The porosity, roughness, gloss, and Cobb value of three types of papers, uncoated, matt-coated, and gloss-coated, were evaluated. Gloss-coated paper had the lowest porosity, while uncoated paper had the highest. Roughness was the highest in uncoated paper and decreased in coated paper stocks. The gloss value increased from uncoated paper to gloss-coated paper. The Cobb value was lowest in matt-coated paper and highest in uncoated paper. Ink drying ability was influenced by press room conditions, machine speed, and colour saturation. No ink drying problem was detected in uncoated and matt-coated papers, while some gloss-coated papers exhibited low set-off.

Keywords: Inkjet, Drop-On-Demand, Piezoelectric Inkjet, Thermal Inkjet, Gloss coated, Matt coated, Substrate

1. Introduction:

Different types of paper present challenges in meeting the end user's requirements due to various finishing treatments that enhance their properties. Paper is a crucial component of print-production methods and accounts for 60-70% of total production costs [1]. Runnability refers to the paper's ability to move smoothly through the press during printing without jamming, influenced by factors such as edge quality, stiffness, and moisture level. Extraneous factors like pressroom conditions and temperature also impact runnability [2]. Paper finish quality has a significant impact on paper quality in digital print production [3].

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1.1 Basic composition and surface properties of inkjet paper

Inkjet paper composition is a crucial factor in producing high-quality colour inkjet images. To meet the higher quality standards demanded by the market, special inkjet printing papers with surface sizing are designed [4]. Design factors such as drop volume, evaporation rate, penetration rate, coating thickness, and porosity need to be balanced in the special inkjet coated media. [5]. The coating structures of inkjet paper vary from simple single-layer coatings to more complex multi-layered structures, including distinct functions like colourant retention and solvent absorbing layers. The ink-absorbing layer, composed of pigment particles and voids, is a critical part of the composition of an inkjet paper sample. However, light scattering from these voids in the ink-absorbing layer can reduce the accuracy of colour reproduction in the image, requiring transparency to minimize light scattering [6].

The properties of inkjet paper include grammage, thickness, surface roughness, whiteness, opacity, strength, porosity, sizing (water absorbency), stiffness, and porosity, with each parameter playing a role in printability and runnability [7]. Inkjet paper surface properties can be affected by both composition and manufacturing process. Paper consists primarily of fibres derived from wood, cotton, or grasses, with two types of wood: "hardwoods" and "softwoods" [8]. For inkjet printing, a paper must possess certain characteristics such as high ink retention on the surface, quick absorption of ink solvent, low colour bleeding into other colours, negligible strikethrough, and moisture and light resistance [9]. The surface of inkjet paper can be classified as either a microporous or swellable ink receiving layer, depending on the nature of the ink receiving layer. This type of paper is usually used with dye-based ink [10].

1.2 Factors Affecting Substrate Runnability:

Runnability is a critical aspect of paper quality as it determines the efficiency and productivity of the printing process [11]. To ensure good runnability, paper must possess key characteristics such as strength, uniformity, flatness, porosity, and defect-free surface [11]. Additionally, surface finishing and optical properties such as gloss, brightness, and opacity impact paper quality and printability [12]. Mechanical and hardwood pulping processes are preferred for producing paper with better optical properties due to the use of shorter fibers [13]. The final step in paper production, calendaring, is essential to minimize voids on the paper's surface and within its structure [13].

Factors affecting substrate runnability include friction, thickness uniformity, and substrate flatness/shape. Friction is primarily determined by surface chemistry and topography, with excess drying leading to sheets sticking together. Different paper types have varying degrees of susceptibility to deformation due to exposure to mechanical stress or moisture [14]. Maintaining a uniform basis weight and caliper is critical for paper runnability as it affects fundamental properties such as strength, stiffness, and optical quality [14, 15]. Flatness, or proper shape, is also crucial to ensure good runnability and presentation of the finished product [16]. Dimensional stability is another important physical property of paper, describing its capacity to withstand dimensional changes in different directions during printing and converting [17].

1.3 Ink Drying Ability

To achieve a high-quality print, it's crucial to consider the ink drying process when printing on porous or non-porous substrates. Neglecting this process may result in poor print quality, including smudging, lack of sharpness, insufficient colour intensity, and fragility. Understanding the ink drying process in detail is essential to prevent such issues. In inkjet printing, the drying of ink can be achieved through either evaporative drying or absorptive drying methods. Evaporative drying involves the evaporation of the solvent component of ink into the atmosphere, while absorptive drying is achieved through the absorption of ink into the pores of the paper via capillary forces [18]. The extent of ink absorption into the substrate and the subsequent drying and stabilization processes of ink on the substrate are critical factors that can significantly affect the visual quality of print results. Therefore, it is important to ensure that the ink film is fully dried before proceeding with any post-printing finishing procedures such as lacquering, coating, folding, or cutting [19].

The selection of the appropriate substrate and ink combination is a crucial step in printing. The physicochemical interaction between paper and printing ink influences the spreading of wet ink as well as its setting and drying. The illustration below shows the drying mechanism of inkjet inks and the difference between the inkjet ink drying and laser printing [20].

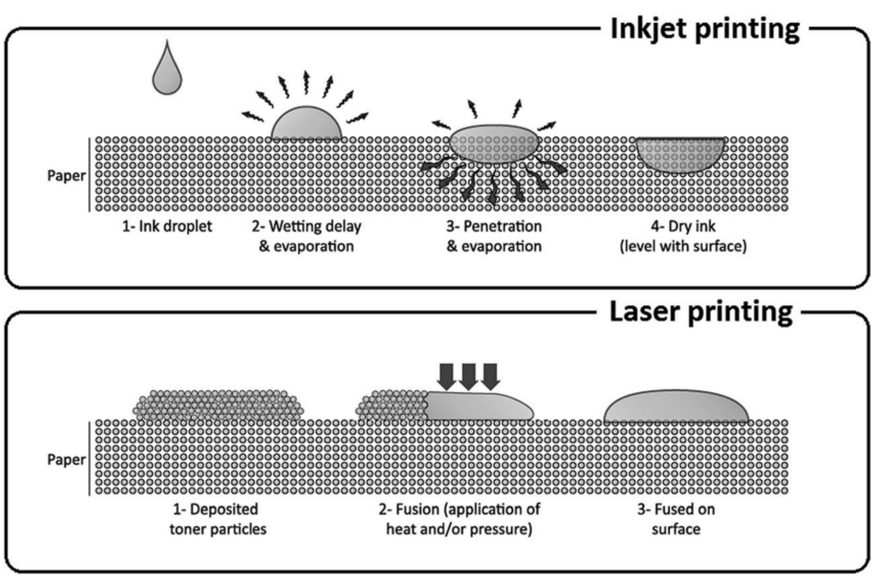

Figure 1 Illustration showing difference (a) between 'wet' ink-jet printing and (b) and the 'dry' process of laser printing.[20]

Furthermore, the ink film's quality parameters, such as ink settling on the paper, print density, print gloss, and colour (CIE Lab*), can be influenced by depth and width variations on the paper surface. The drying rate of ink is influenced by the solvents and ink structure as well as by environmental factors such as air, temperature, and humidity [21]. To achieve optimal drying or curing, several processes, including absorption, radiation, and evaporation can be used. Poor ink drying can result in ink smudging, bleeding of ink, cockling of sheets, and fading of printing, which can significantly affect the quality and durability of the printed output and lead to reprints or additional printing costs.

2. Research Objective

Runnability has a direct relation with consistency in print quality. The objective of this paper is to investigate the factors that affect runnability in inkjet print engines and to analyze the correlation of the paper surface characteristics with the ink drying ability and runnability. As paper is a crucial material in printing, the type and structure of paper used, as well as uninterrupted paper feeding, significantly impact print quality. This study is focused on the surface characteristics of uncoated, gloss-coated, and matt-coated papers and their correlation with ink drying ability and runnability in DOD inkjet print engines. The aim is to provide insights that can help achieve optimum print quality in inkjet printing.

3. Research Methodology

The research methodology adopted for this study involved several steps. Firstly, three types of paper were selected out of four samples from each category - uncoated (90 gsm), both side matt coated (90 gsm), and both side gloss coated (88 gsm) and their surface properties were tested in a standardized laboratory (Table 2). The papers with values closest to ISO 12647-2 were then chosen for printing work under piezo and thermal inkjet print heads. A test chart was prepared using Corel Draw Graphics Suite 2020, incorporating various print elements, and 20 standard observers with normal vision were selected for the experiment based on the FM100 hue test. The printing of the test master on the selected papers was carried out on DOD presses based on piezo DOD inkjet (Oce Canon (Kyocera KJ4B), and thermal DOD Hewlett Packard (A53 HDNA) under standard pressroom conditions on calibrated machines by highly professional operators. During printing, the runnability and ink drying ability of the different paper stocks were monitored. The ink drying ability was evaluated by a subjective visual inspection method, where printed sheets were inspected for any signs of ink smudging, bleeding, cockling, set-off and fading. The observer rated the extent of the defects using a subjective Likert scale (Table 1). The data collected from the standard observers were tabulated and analyzed to determine the mean value and standard deviation of the defects, and the same was represented in graphical format for easy understanding. The research methodology adopted aimed to study various factors affecting the runnability in inkjet print engines and to correlate the surface characteristics of different papers with their runnability and ink drying ability in DOD inkjet print engines.

Table 1 Likert Scale for measurement of ink drying ability

Defect	Rating "1"	Rating "2''	Rating "3"	Rating "4''	Rating "5"
Ink smudging	No smudging observed	Low smudging observed	Moderate smudging observed	Significant smudging observed	High smudging observed
Ink bleeding	No bleeding observed	Low bleeding observed	Moderate bleeding observed	Significant bleeding observed	High bleeding observed
Cockling	No cockling observed	Low cockling observed	Moderate cockling observed	Significant cockling observed	High cockling observed
Set-off	No Set-off	Low Set-off observed	Moderate Set-off observed	Significant Set-off observed	High Set-off observed
Fading	No fading observed	Low fading observed	Moderate fading observed	Significant fading observed	High fading observed

4. Data Collection and Analysis

The data for various surface characteristics of the selected papers is presented in Table 2. The table 2 presents various physical properties of three paper samples - Sample 1 (matt coated), Sample 2 (gloss coated), and Sample 3 (uncoated). These properties can be broadly categorized into four groups:

1. Basic properties: The basic properties of the samples include GSM (gram per square meter) and thickness. These properties help in determining the weight and thickness of the paper samples.
2. Strength properties: The strength properties of the samples include Burst Factor, Tensile Strength, and Tear Factor. These properties help in determining the strength and durability of the paper samples. Tensile strength is measured in both machine and cross directions.
3. Surface characteristics: The surface characteristics of the samples include Porosity, Roughness, Brightness, Whiteness, Yellowness, Gloss, and Opacity. These properties help in determining the surface quality of the paper samples. Porosity is the measure of air permeability through the sample, and Roughness measures the smoothness or

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roughness of the surface. Brightness, Whiteness, and Yellowness represent the colour of the paper, while Gloss measures the reflectivity of the surface. Opacity measures the ability of the paper to prevent the passage of light through it.

4. Water resistance: The water resistance property of the samples is determined by Cobb Value, which measures the quantity of water absorbed by the paper samples.

Table 2 Paper testing data of various surface characteristics of different paper stocks

Sr. No.	Property	Standard Procedure	Unit	Direction	Sample 1 (Both side matt coated)	Sample 2 (Both side gloss coated)	Sample 3 (Uncoated)
1	GSM	Tappi Test Method T 410	g/m^2	-	90.8	88.0	90.9
2	Thickness	IS: 1060:1	um	-	64	56	99
3	Burst Factor	IS: 1060:1	-	-	15.8	14.8	14.3
4	Cobb value	IS: 1060:1	g/m^2	Top	35.7	30.0	45.7
				Bottom	33.5	27.4	44.1
5	L*	T 524	-	-	86.6	85.5	79.3
6	a*	T 524	-	-	1.1	0.8	1.2
7	b*	T 524	-	-	-13.5	-11.0	-13.9
8	Porosity	T 547	ml/min	-	127.8	108	140
9	Roughness	ISO 8894	ml/min	Top	11.9	10.0	14.9
				Bottom	11.3	9.5	17.5
10	Brightness	IS: 1060:2	%	Top	80.6	82.6	77.8
				Bottom	81.1	84.8	76.9
11	Whiteness	T 562	%	Top	83.1	80.5	76.7
				Bottom	81.4	79.7	75.9
12	Yellowness	T 1256	%	Top	13.4	12.0	9.3
				Bottom	13.1	10.0	9.8
13	Gloss	IS: 1060:1	%	Top	45.3	53.8	37.1
				Bottom	41.4	49.0	28.7

14	Opacity	IS: 1060:1	%	-	85.1	88.1	91.6
15	Tensile strength	IS: 1060:1	Nm/g	Machine direction	61.1	68.24	67.78
				Cross direction	47.9	52.13	41.75
16	Tear factor	IS: 1060:1	-	Machine direction	29.4	29.44	27.9
				Cross direction	31.7	36.32	30.6

Comparison of Different Paper Characteristics: -

Porosity: - From the table 2 and figure 2 it is clear that the porosity is least in gloss coated paper. The data shows that porosity is maximum in case of uncoated paper and when we move towards uncoated to matt coated paper stocks the porosity keeps on decreasing. The main reason behind this can be attributed to the presence of coating pigments on the surface of the coated paper which fills the gaps between intermeshed fibres.

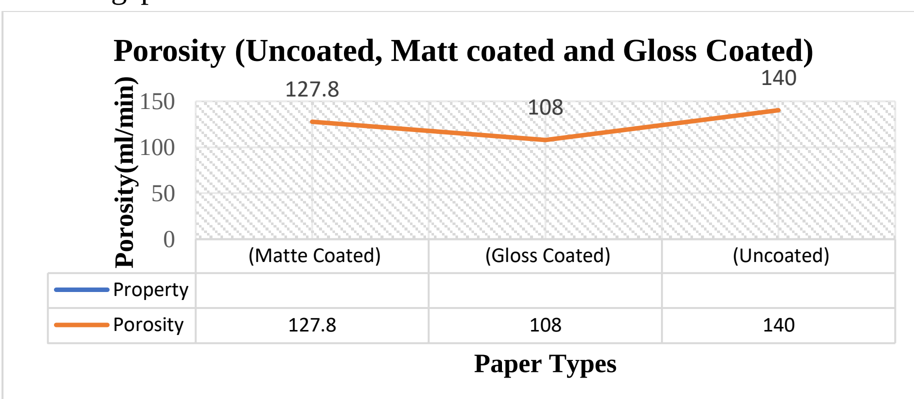

Figure 2 Porosity of different paper types

Roughness: - The roughness of the papers is shown for all three types of papers for top and bottom side. The main function of coating is to fill the void between the fibres. Rough surface poses the risk of mechanical interlocking between the sheets, which may obstruct the feeding. Extra smooth surface creates a larger contact area between the sheets, which might enhance the interlocking caused by surface chemistry. The data presented in Table 2 and Figure shows that the roughness of uncoated paper is maximum. It reduces when we move from uncoated to coated paper stocks. Gloss coated papers exhibits least surface roughness on both sides.

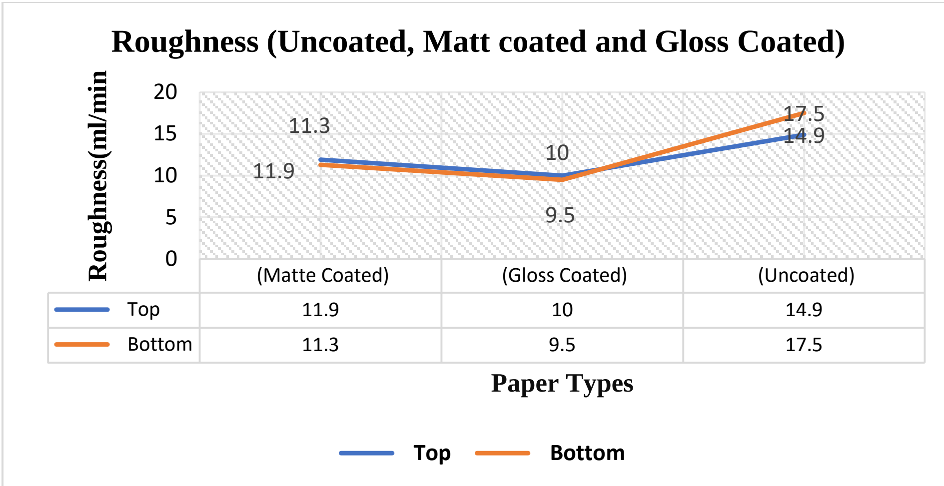

Figure 3 Roughness of different paper types

Gloss: - Gloss is the reflection of specular light from a paper surface. There is a direct correlation between micro- and macro-smoothness of a paper and its gloss. Compared to uncoated paper, gloss coated paper had a gloss increase of 53.8%. There were similar patterns on both the top and bottom surfaces of the paper. As compared to the top side, the bottom side of the paper has a smaller percentage of gloss. The results are shown in Table 2 and Figure 4.

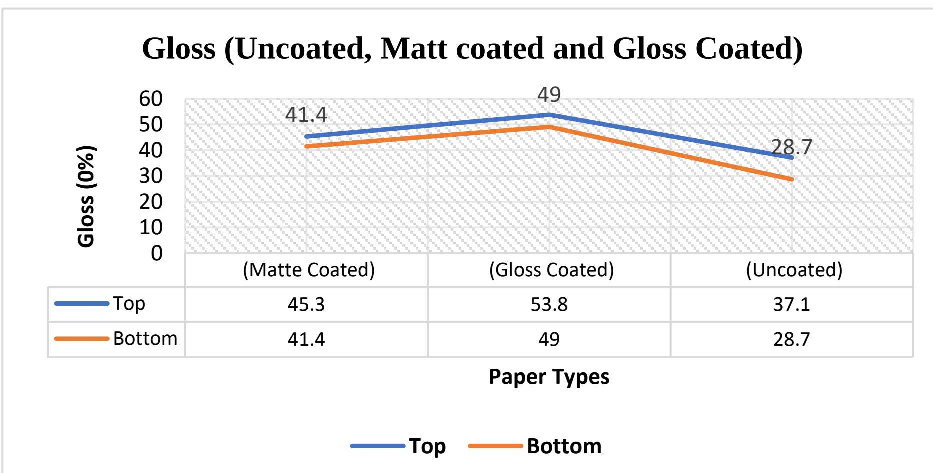

Figure 4 Gloss of different paper types

Cobb Value: - The Cobb value reveals details about the paper samples' ability to absorb water. The Cobb test measures how much water, over a specified period of time, is absorbed by a specific area of paper in one-sided contact with water. Contact times of 60, 180, and 1800 seconds are typical, depending on the material. The paper needs to be sized in order to attain specific Cobb values. Adding or applying additives (sizing agents) by mass sizing or surface sizing results in a partial hydrophobization. According to the results, gloss coated paper has the lowest cobb values (top side: 30.0 g/m2, bottom side: 27.4 g/m2), and uncoated paper has the

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highest cobb values (top side: 45.7 g/m2, bottom side: 44.1). The matt coated paper exhibits the Cobb value of 35.7 g/m2 and 33.5 g/m2 for the top and bottom sides, respectively. The results are presented in Table 2 and Figure 5.

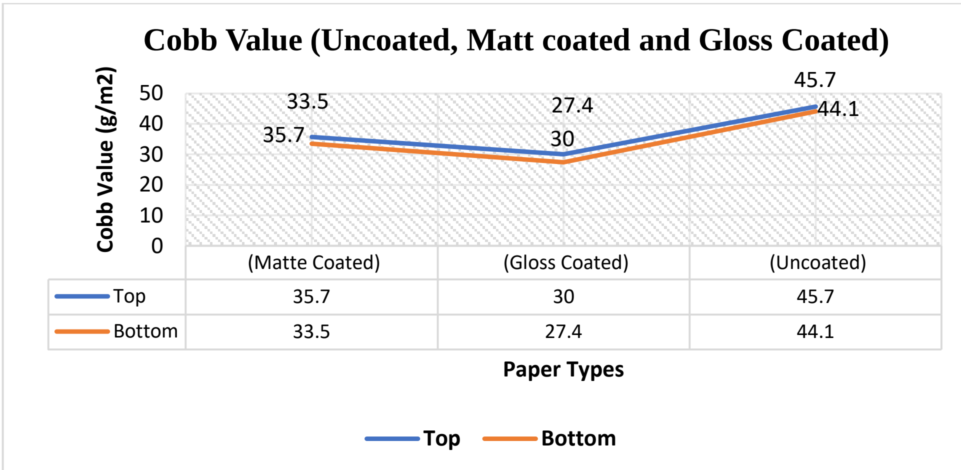

Figure 5 Gloss of different paper types

Results & Discussions

The surface characteristics values of selected types of papers shows that the uncoated paper substrates have maximum porosity among matt coated and gloss coated papers. The gloss percentage value of gloss paper is maximum followed by matt coated and uncoated papers. The comparison of different paper characteristics showed that the porosity was least in gloss coated paper while the roughness of uncoated paper was maximum. The gloss increased from 28.7% to 53.8% when moving from uncoated paper to gloss coated paper. The Cobb test revealed that matt coated paper had the lowest cobb values while uncoated paper had the highest cobb values. The gloss paper exhibited the Cobb value of 30 g/m2 and 27.4 g/m2 for the top and bottom sides, respectively. From the results (Figure 6, 7 & 8) it can be inferred that all three types of papers (uncoated, matt coated, and gloss coated) show good runnability and excellent ink drying abilities in continuous inkjet (CIJ), piezoelectric inkjet (PIJ) and thermal inkjet (TIJ) technologies. However, some differences were observed among the papers in terms of their surface characteristics.

The uncoated papers showed maximum porosity and were more prone to smudging, bleeding, and cockling due to their porous and absorbent nature. On the other hand, matt and gloss coated papers were generally more resistant to these problems. Coating pigments fill the gaps between intermeshed fibers, reducing porosity and improving surface smoothness, which prevents smudging and bleeding. The smooth surface of matt coated papers allowed the ink to sit on the surface of the paper, drying more quickly and with less bleeding.

Although the overall results were excellent for all types of papers, a slight presence of set-off

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was observed in a few gloss coated sheets, which may have been due to the pressure exerted by the top sheets as the pile height increased. This indicates that care must be taken when handling gloss coated papers to avoid such issues.

The results of the study clearly indicate that both heads (PIJ and TIJ) of inkjet printing machines do not have any issues with the drying of ink. However, the surface characteristics of the paper, such as porosity and roughness, affect the ink-drying ability and other aspects of print quality. Print production efficiency can be enhanced by selecting the appropriate paper substrate based on the specific printing application and desired print quality.

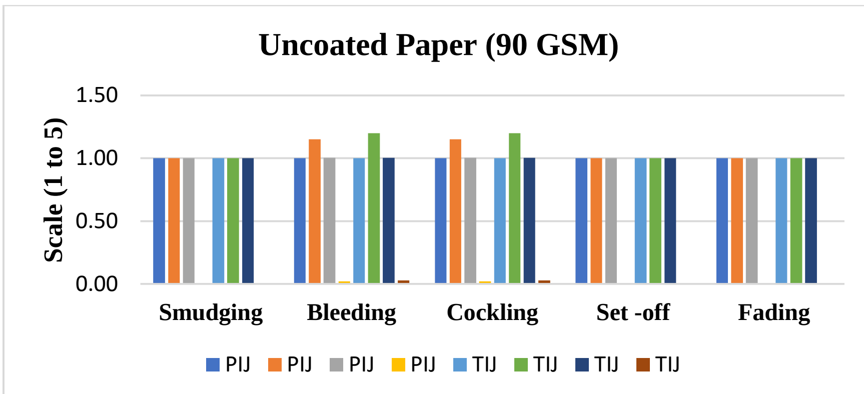

Figure 6 Ink drying ability observed values on uncoated paper

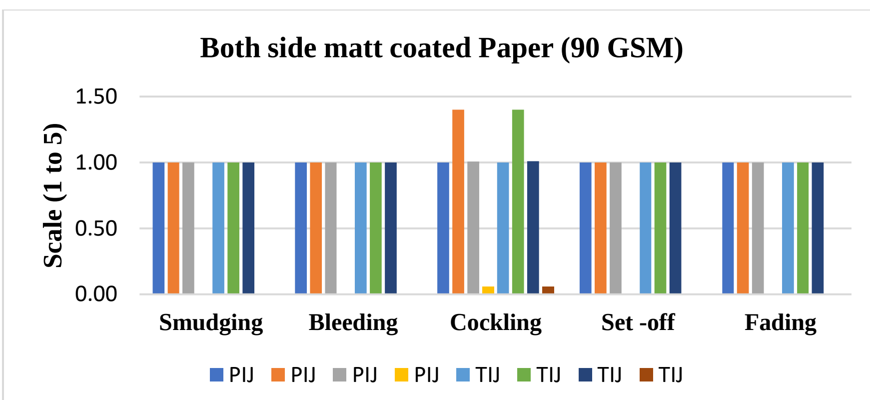

Figure 7 Ink drying ability observed values on matt coated paper

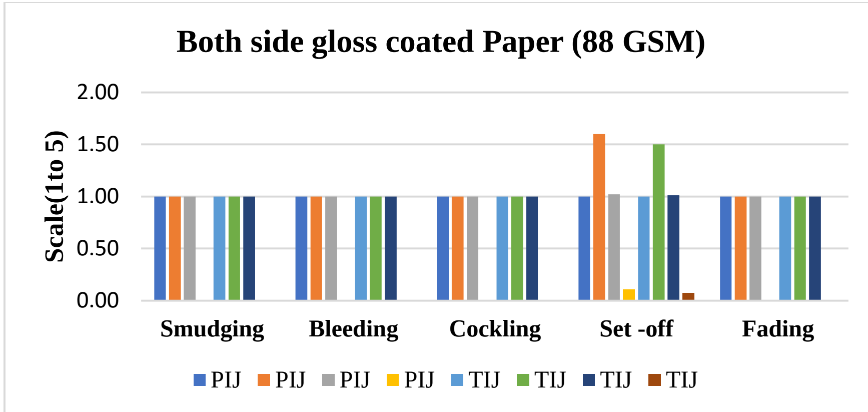

Figure 8 Ink drying ability observed values on gloss coated paper

Conclusion

Runnability related issues are very common across all printing processes, but some of them are highly specific to digital printing. In this study, ink drying ability and runnability related issues of uncoated, matt coated, and gloss coated paper stocks were investigated using two types of inkjet printing machines. The results showed that all three paper types exhibited good runnability during printing with no significant differences between the PIJ and TIJ technologies. Uncoated paper had no ink drying problems but was more prone to smudging, bleeding, and cockling due to its high porosity and roughness. In comparison to matt coated and uncoated papers, gloss coated papers have a smooth surface and minimal porosity. On both inkjet press types, PIJ and TIJ, coated stocks performed better in runnability-related tests, while uncoated papers dried ink well.

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