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ORIGINAL ARTICLE

Coloration Technology

Effects on print quality of varying acrylic binder types in water-based flexographic ink formulations

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Abstract

The ink industry is one of the world's largest markets due to the increasing demand for printing inks for the packaging industry. Flexography printing is a well-known promising technology for large-area printing due to its high printing speed and roll-to-roll capability to print economically on a variety of surfaces and is used in nearly in all areas of packaging printing. Water-based inks are considered non-toxic, odourless, and more environmentally friendly options compared to solvent-based inks. Therefore, in this article, the goal was to develop new water-based ink formulation with different acrylic binders for flexographic printing on commercial solid bleached sulphate (SBS) board. Five inks were formulated with four different acrylic binders and compared to a commercially available ink to study their performance. The developed inks were investigated with regard to their print qualities and print characteristics. It was found that the binder type influenced some print quality while the effect was not significant for others. Using flexography printed cyan inks, the ink formulated with the highest molecular weight had the lowest print density and the largest tonal value increase (TVI) observed between 40 and 60 tone values. The same ink had the largest mottle values and variation in topography. For values of print contrast and delta gloss at 75°, although differences were observed between average values, data had inconclusive variation and spread around averages, where no conclusive trends or effects of acrylic binder type on these response factors were observed. Print chroma and dot roundness results were equally close for all printed samples.

1 | INTRODUCTION

Graphic printing technologies are used to meet the ever-increasing market demand for packaging. This rate covers about half of all graphics production.[1] While the growth of the printing industry has slowed in recent years with digitalisation, the packaging industry continues to grow with a great acceleration[2] and its global future looks bright. Efforts are always put to raise the quality of prints and to increase the speed of production. Flexography printing is a well-known promising technology for large-area printing due to its high printing speed and roll-to-roll capability to print economically on a variety of surfaces.[3] Nowadays, flexography printing is used in more than 75% of packaging products.[4] Traditionally, flexography (flexo for short) is considered a relatively simple printing technology. However, since currently the market of printing production is tending towards the intensive use of flexographic printing, attributed to the rapid development pace of the packaging industry, more problems and challenges arise that need to be addressed, explored, and solved.[5]

Flexography is used nearly in all areas of packaging printing, such as labels, food packaging,[6] disposable paper goods, corrugated containers, folding cartons, paper sacks, plastic bags, milk and beverage containers, disposable cups and containers, labels, envelopes, newspaper, and packaging found in every grocery store. It has the advantage of achieving high quality print results on a whole range of printing substrates, such as polypropylene plastic films[7] and various other plastic films, such as polyethylene, and many complex sandwiched film structures,[8] aluminium foil,[9] corrugated cardboard, and on "orodispersible" films in the pharmaceutical industry.[10] Flexographic printing on paper substrates for packaging material can be based on environmentally friendly acrylic binders and contain inorganic fillers with platelet particles incorporated in the polymer matrix.[11]

Today, customers are more enlightened and more aware of the environmental impact of consumer products. They do not only take into consideration quality of products but also product safety, environmental impacts, and recycling of used packaged products.[12] One aspect of packaging is the ink formulation used in printing, which we will cover next for flexographic printing.

Flexographic inks can be divided into three categories based on their chemistries: solvent ink, water-based ink, and ultraviolet (UV)-curing ink,[13,14] which are all widely used. Water-based inks are considered non-toxic, odourless, and more environmentally friendly options compared to solved-based inks that contain volatile organic compounds as part of their formulation. Therefore, for ecological reasons, water-based inks are being considered as the most sustainable printing ink with high solid content and low-viscosity advantages.[15] Thus, attention in the printing industry is concentrated on the production of water-based and water-reducible printing inks.[16] Water-based inks are currently used in the packaging industry; however, more research is needed to overcome some of the faced challenges. These challenges include the complex preparation process and high cost, water-based ink, pigment and printing method.[17] In general, the type and amount of polymer binders and hence the properties of formulated inks have profound effects on print quality.[18] The binders in printing ink have multiple functions and to improve the ink performance, multiple resins/polymers are applied as the binders. They have many functionalities including dispersing the pigments in the support material and binding it on the printing surface and as well as modifying the rheological and mechanical properties of the printing inks. Resins also determine end use properties such as gloss, hardness, attachment of ink to the printed substrate and adhesion.[18] Water-based inks for flexography are made with acrylic acid, and polymers and copolymers made from it, such as acrylate, methacrylates, polyester acrylates, and polyurethane acrylates.[18] The common acrylic resins used in water-based inks are acidic and not soluble in water. They become soluble when alkaline materials are added to them.[19] These water-based inks (with acrylic resins) have a hydrophilic character.[20,21] In this article, we study the effect of different formulated flexography water-based inks on the most relevant parameters of print quality: print density, contrast, chroma, brightness and tonal value increase. Other print characteristics such as mottle, topography, and dot roundness were also measured.

2 | METHODOLOGY AND MATERIAL

After commercial SBS boards were conditioned at 24 h at 50% relative humidity and 23°C (73.4°F), using a Parker Print-Surf (PPS) tester at 1000 kPa clamping pressure with a soft backing PPS porosity was measured. Then, the thickness values of the samples were measured with a TMI micrometer (Testing Machines Inc., New Castle, DE, USA). Next, using values obtained from the PPS porosity and thickness[22] the air permeability values of the samples were calculated. Using a PPS ME-90 (1000 kPa, soft backing), the roughness values of the sample according to TAPPI T555-OM-99 were measured. On TAPPI Standard T452-OM-98, using a Brightimeter Micro S-5, the brightness of the sample at 457 nm wavelength was measured. Lastly, the samples gloss was measured using a Novo-Gloss™ Glossmeter based at 75° according to TAPPI standard T480-OM-99. Table 1 shows that the physical and optical properties of used-SBS board.

Table 2 gives the physical and chemical properties of the pigment dispersions used in printing. The pigment (colourant) is a cyan ink pigment dispersion provided by American Inks & Technology Ltd (Portage, MI, USA). A total of four acrylic binders were investigated in this study: commercial acrylic resin (CAR), commercial low molecular weight acrylic resin (LMWAR), commercial medium molecular weight acrylic resin (MMWAR), and commercial high molecular weight acrylic resin (HMWAR). Table 3 shows the chemical properties of these binders.

2.1 | Ink formulation

Five water-based inks were prepared following the same formulation shown in Table 4 but each with a different binder. F1 to F5 were assigned to the formulated inks based on the type of binder used. A commercial ink (CI) was used as the primary reference, or the control. The CI was provided from Wikoff Colour Corporation. F1 is a CAR, F2 an ink with LMWAR, F3 an ink with MMWAR, F4 an ink with HMWAR, and F5 an ink with a combination of MMWAR and HMWAR (25% MMWAR, 15% HMWAR, and 8.1% deionised water).

In all formulations, the pH was adjusted with 5% ammonia water to pH 9. Viscosity was measured as efflux time—on Zahn cup 2 at controlled temperature 25°C and the efflux time was adjusted to 30 s. Other common ink components added to the formulations were isopropyl alcohol, defoamer (FC-613), acrylic varnish, wax, and ammonium hydroxide (NH_4OH).

2.2 | Printing conditions

In the Flexiproof 100 device which is comparable to a single-colour printing press, prints on SBS board using commercial cyan ink was performed. The photopolymer printing plate used for printing was 260 mm × 90 mm in size and thickness value of 1.7 mm. The pressures in Flexiproof 100 device were 45 units between anilox roller and plate cylinder, and 50 units pressure between plate cylinder and impression cylinder. The printing speed was set constant at a speed of 40 m/min. The plate screen frequency was 39.37 L/cm (100 lpi). The anilox cylinder screen frequency was 200.6 L/cm (510 lpi). The capacity of its ink-cells was 5 cm^3/m^2 (μm).[23] The quality of printed samples in terms of print density, print contrast, dot gain and CIE $L^*a^*b^*$ values were used to evaluate using an X-rite eXact device in M1 mode using D_{50} light

TABLE 1 The optical and physical properties of solid bleached sulphate (SBS) board

Properties	Average	Standard deviation
Brightness (%)	78.67	0.40
CIE L^*	94.53	0.18
CIE a^*	−0.21	0.05
CIE b^*	3.52	0.10
Specular gloss 75°	23.5	0.81
Roughness (μm)	5.92	0.23
Parker Print-Surf porosity (ml/min)	256.60	12.63
Thickness (μm)	353.60	6.10
Permeability ($μm^2$)	0.00443	2.73×10^{-4}
Tearing resistance (mN)	406.40	18.24
Bursting strength (kPa)	68.80	1.10
Tensile strength (kN/m)	30.10	3.28

TABLE 2 The physical and chemical properties of pigment dispersion

Appearance	Blue liquid
pH	9.0
Solubility in water	Miscible
Density (g/cm^3)	1.11
Viscosity (mPa s)—(centipoise)	20

TABLE 4 A standard water-based flexographic ink formulation

Material	Weight (g)
Pigment dispersion PB-15-44 (blue)	43.5
H_2O (deionised water)	7
Acrylic binder	48.1
Wax (AIT-PE-35)	1
Defoamer (FC-613)	0.4
Total weight	100

TABLE 3 The chemical properties of acrylic resins used in ink formulations

Acrylic type	Non-volatiles (%)	pH	Acid[a]	Molecular weight (Da)
CAR	Not available—proprietary			
LMWAR	34	8.5	215	8500
MMWAR	49	8.5	58	~10,000
HMWAR	33	8.5	120	>200,000

Abbreviations: CAR, commercial acrylic resin; HMWAR, commercial high molecular weight acrylic resin; LMWAR, commercial low molecular weight acrylic resin; MMWAR, commercial medium molecular weight acrylic resin.

[a]Amount in milligrams of potassium hydroxide (KOH) needed to neutralise 1 g of resin.

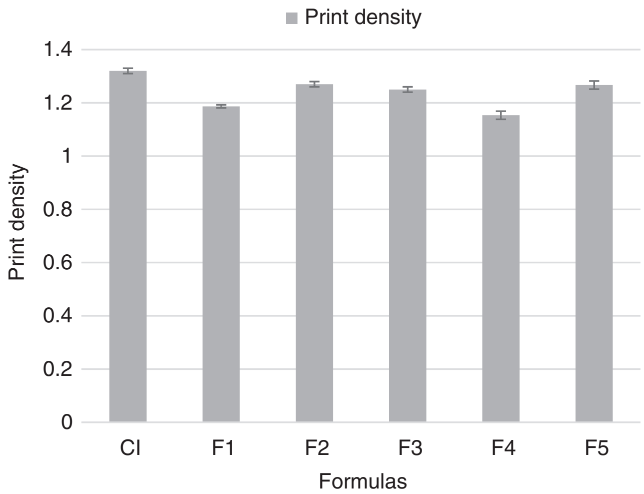

FIGURE 1 Effect of binder type on print density.

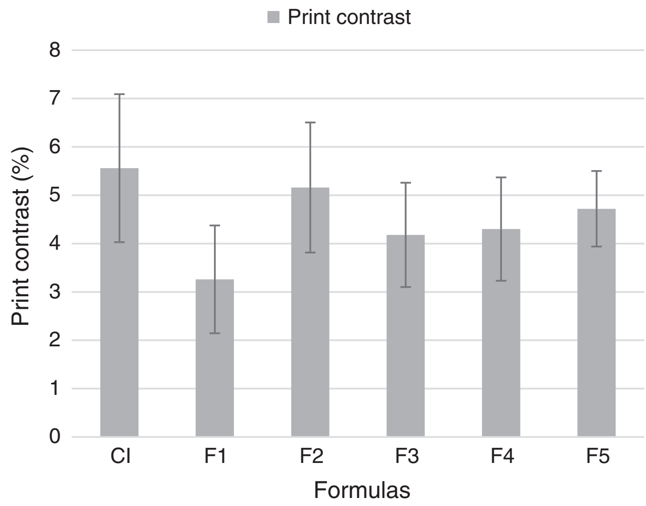

FIGURE 2 Effect of binder type on print contrast.

source under an observation angle of 2°. Using a BYK micro-gloss meter the unprinted and printed gloss values at 60° based on ASTM D523 were measured. Also, using a Novo-Gloss™ Glossmeter based on TAPPI standard T480-OM-99 the unprinted and printed gloss values at 75° were measured. After that, using the measured values the delta gloss values were calculated.[24] Using an Epson Perfection V500 Photo scanner software at 600 ppi with Verity IA Print Target version 3 software with stochastic frequency distribution analysis (SFDA) algorithm on the solid patch the print topography and mottle values of test samples were measured.[25] Rub resistances values of printed samples were measured from unprinted SBS/printed SBS and 60 strokes based on BS 3110:1959 standard by Sutherland Ink Rub with a load of 4 lb. weight.[26]

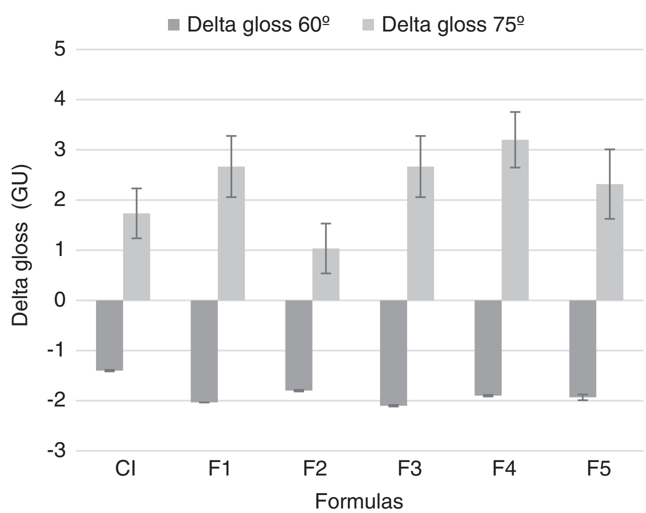

FIGURE 3 Effect of binder type on delta gloss.

3 | RESULTS AND DISCUSSION

Five cyan ink samples were prepared with the same formulation except for binder type. The effect of binder on print quality was examined by measuring print density, print contrast, gloss, print chroma, and tonal value increase (TVI). Results were compared each time to those of CI. Figure 1 shows the print density of printed solid samples. For print density, the higher the number, the thicker (denser) the ink film, based on higher absorption of incident light of complimentary colour of printed colour. It can be noticed that print density for samples printed with F4 ink (with HMWAR) was the lowest compared to other inks. This could be explained by the high molecular weight of the binder (> 200,000) and the high viscosity of the ink that affected the ink transfer from the anilox rolls and hence the thickness of the printed film. While F4 showed the lowest print density out of all printed inks, there was not a large difference in values among the other printed formulations. The CI showed the largest print density out of all formulations.

When it came to print contrast as shown in Figure 2, ink F1 showed the lowest measured value, however, there are large variations in the data. Therefore, we cannot conclude that the binder in these inks had a significant impact on print contrast.

Print gloss is an important component of print quality that depends not only on the substrate being printed but also related to the ink holdout and the ink setting.[27] In printing, the term "delta gloss" describes the difference in gloss between the printed and the unprinted substrate. For inks, the binder is a predominant component affecting ink viscosity.[28] Therefore, viscosity and hence ink levelling and setting rate may affect print gloss. To study this among the different binder type formulations, the change of delta gloss between printed ink samples was measured and results are shown in Figure 3. For delta gloss at 60°, one can see a lower delta gloss for printed CI compared to other formulated ink samples. This might be due to CI ink film levelling better and smoother before the structure is set, resulting in a smaller negative delta gloss. For delta gloss at 75°, formulated inks F1, F3, F4 and F5 showed the larger delta gloss values especially compared to that of F2. The sign difference between delta gloss at 60° and at 75° is that printers measure print-paper, while papermakers measure paper-print. According to Table 3, F2 has the lowest molecular weight among the others (F3–F5). Lower molecular weight leads to lesser ink levelling, thus smaller gloss. This could be one factor, but additional investigation is needed here.

In printing, CIE print chroma ($C^* = \sqrt{a^{*2} + b^{*2}}$) is a measure of saturation, which describes the intensity or purity of a colour. Print chroma was measured for all printed cyan inks. Results were very close for all printed samples (Figure 4) and hence, one cannot see an influence of binder type in ink on print chroma.

The ΔE value indicates the colour difference between the displayed colour and the original colour. A low ΔE value indicates that the colours are very close to each other, while a very high value indicates a difference between the colours.[29,30] A $\Delta E \leq 1$ indicates a colour difference that cannot be perceived by the human eye. A ΔE

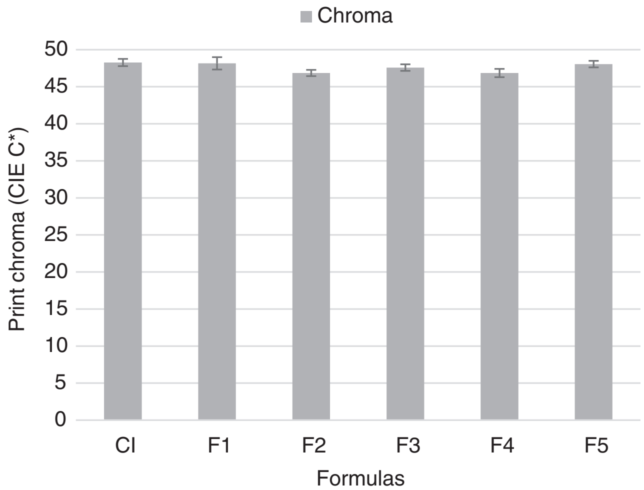

FIGURE 4 Effect of binder type on print chroma.

TABLE 5 The CIE $L^*a^*b^*$ colour values of printed test samples

Type of ink	L^*	Standard deviation	a^*	Standard deviation	b^*	Standard deviation	ΔE_{00} print
CI	42.0	0.7	−12.4	1.0	−46.7	0.3	—
F1	46.8	0.6	−16.5	1.1	−45.2	0.6	5.2
F2	43.2	0.7	−12.7	1.0	−45.2	0.2	0.5
F3	46.0	1.3	−16.0	1.3	−44.8	0.3	4.1
F4	47.3	1.6	−15.5	0.9	−44.2	0.4	5.0
F5	44.5	0.9	−14.6	0.7	−45.8	0.4	2.8

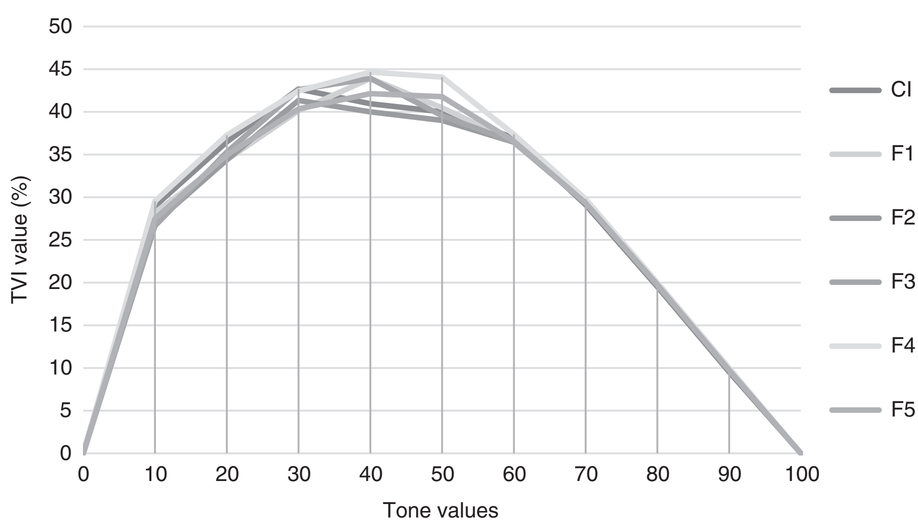

FIGURE 5 Effect of binder type on tonal value increase (TVI).

TABLE 6 Print topography and mottle properties of printed test samples

Type of ink	Print topography	Print mottle	Area of interest (cm^2)	Resolution (ppi)
CI	5.60	2.60	22.36	600
F1	12.10	3.00	22.36	600
F2	11.70	3.10	22.36	600
F3	13.50	2.80	22.36	600
F4	18.30	4.30	22.36	600
F5	8.00	2.50	22.36	600

value between 1 and 2 indicates a colour difference that can only be detected with close observation with a measuring device, ΔE difference between 2 and 3 indicates a colour difference that cannot be easily distinguished from the standard colour by most observers. A ΔE difference of 3 or higher indicates a colour difference perceptible to the observers.[31]

Table 5 shows the CIE $L^*a^*b^*$ colour values of printed cyan inks. Print ΔE_{00} was calculated according to Equation 1. $\Delta E_{00} = 5.2$ was obtained for F1, $\Delta E_{00} = 0.5$ for F2, $\Delta E_{00} = 4.1$ for F3, $\Delta E_{00} = 5.0$ for F4, and $\Delta E_{00} = 2.8$ for F5. The lowest ΔE difference obtained in F2 indicates that a colour value closest to the original colour is obtained, a colour difference that is difficult to notice with the eye is obtained in F5, and a noticeable colour difference is obtained in other formulations.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)} \quad (1)$$

where R_T represents a hue rotation term; K_L, K_C, and K_H the parametric factors; L', C', and H' the compensation for neutral colours; S_L compensation for lightness; S_C compensation for chroma; S_H compensation for hue.

To define more of print quality and to provide more effective appearance-based targets for the presswork, TVI (also known as dot gain) can be measured and plotted at several points throughout the tone value scale. There are many factors that can negatively affect TVI and cause too much dot gain, such as printing plate pressure, packing or type of plate blanket for offset, substrate, and viscosity of ink. TVI was measured and the results are shown in Figure 5. The most obvious difference in results is shown between 40 and 60 printed tone values. F4 ink with HMWAR has the largest ink spread and dot gain out of all formulated inks, due to higher thixotropy of high molecular weight resin. This agrees with print density results (Figure 1). It seems that F4 ink spreads the most

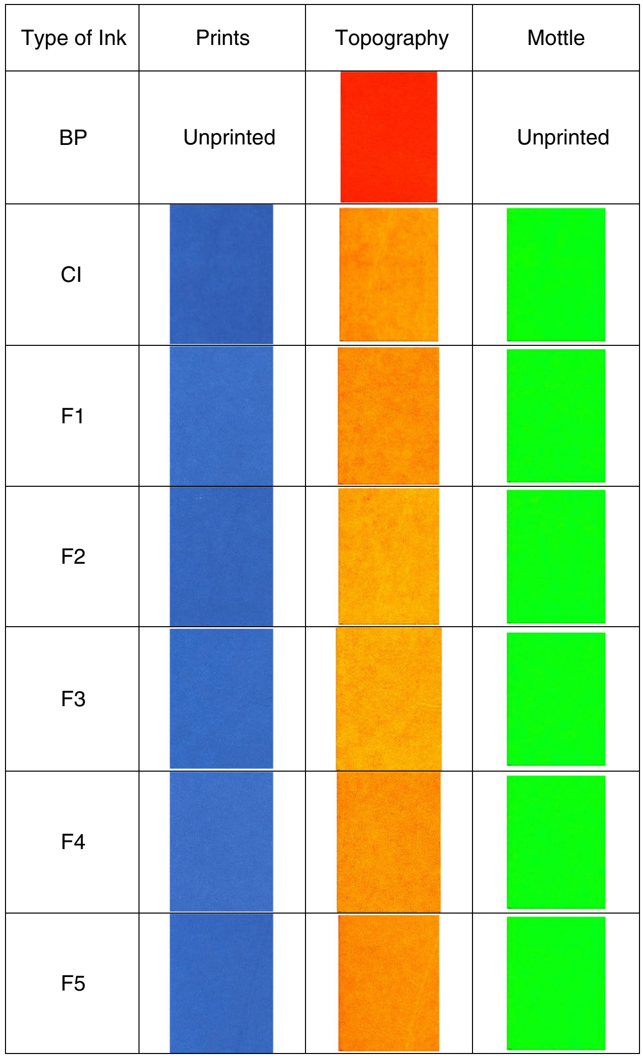

FIGURE 6 Print topography and mottle images of printed test samples. BP, base paperboard; CI, commercial ink

after printing resulting in the largest TVI and lowest print density compared to other formulated inks.

Print mottle, which is an important aspect of print quality, is a defect usually the result of uneven non-uniform ink absorption across the surface. Especially, it is visible in areas of uniform colour such as solids and continuous-tone screen builds. Ink type, paper type and surface properties, the printing process is influenced by many parameters, such as binder migration to the coated paper surface.[25] Print mottle was measured on solid patches of printed ink samples. Quantitative results, print topography and mottle values are summarised in Table 6. We can see that both print topography (18.30) and mottle (4.30) were the worst with printed F4 ink. This is again in accordance with previous print density and TVI results observed with F4 formulation as print mottle is a printing defect that generally relates to ink spreading and print density unevenness across the whole

TABLE 7 Dot measurements of 15% screen dots of printed test samples

Type of ink	Dot area (mm^2)		Dot roundness (%)		Equivalent diameter (μm)		Aspect ratio	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
CI	150.46	53.34	73.50	12.59	138.41	37.96	0.98	0.21
F1	151.26	30.08	76.50	9.19	138.61	22.43	0.96	0.17
F2	165.92	22.38	78.50	7.45	145.30	12.97	0.98	0.11
F3	156.70	18.69	80.50	6.79	141.25	10.65	0.96	0.09
F4	160.35	29.92	77.25	9.43	142.87	20.48	0.93	0.13
F5	152.67	34.02	78.00	8.41	139.42	25.38	0.96	0.11

TABLE 8 Print rub resistance properties of printed test samples

Type of Ink	Density before rub testing	Standard deviation	Density after rub testing	Standard deviation	Rub resistance (%)
CI	1.32	0.01	1.31	0.01	99.24
F1	1.19	0.01	1.18	0.01	99.19
F2	1.27	0.01	1.26	0.01	99.21
F3	1.25	0.01	1.24	0.03	99.20
F4	1.15	0.02	1.14	0.01	99.13
F5	1.27	0.02	1.25	0.01	98.68

print. As seen before, F4 ink spreads the most and had the lowest print density among all formulated inks.

Visual results are shown in Figure 6 for images obtained using the VERITY IA Print Target software. In Figure 6, cyan colour shows printed image, orange colour shows print topography, and green colour shows print mottle. When the topography of the formulations is examined, it is seen that the colour code becomes more orange. This indicates that the surface smoothness obtained at this pressure has increased. It is seen that the highest colour change is in F4, and the lowest colour changes are in F2, F3 and F5.

The dot circularity (also referred to as roundness) was measured at printed 15% screen dots by Paxit. The results are summarised in Table 7. All dot roundness averaged between 73.5% for CI and 80.5% for F3 ink with some variation and spread of results translated by the standard deviations. Therefore, we cannot see a significant difference between averages of dot roundness with different printed ink formulations.

Rub resistance was calculated by comparing colour density before and after rubbing according to Equation 2. Calculated values were around 99% for all printed ink samples and hence, ink rub resistance was not influenced by acrylic type in all ink formulation (Table 8).

$$\text{Rub resistance}\,(\%) = \frac{\text{Density after rub}}{\text{Density before rub}} \times 100 \quad (2)$$

4 | CONCLUSIONS

Water-based flexographic inks were developed based on acrylic binder types differing in their molecular weights. Water-based inks were considered here as they are considered to be non-toxic, odourless, and more environmentally friendly options compared to solvent-based inks. It was found that the binder type influenced some print quality, while the effect was not significant for others. Among all inks, ink formulated with the highest molecular weight resin had the lowest print density and the largest TVI observed between 40 and 60 tone values. The same ink had the largest mottle values and variation in topography. When it came to other print characteristics such as delta gloss at 75°, contrast, chroma, and dot roundness, either no difference was observed, or average values were different but with large variation and spread of data to conclude any trend or effect of acrylic binder type on these response factors.

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