RECYCLING OF PRINTED PAPERS AND USABILITY IN FLEXO PRINTING PACKAGING

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This study aimed to determine whether 100% recycled papers can replace papers made from virgin fibers for the purpose of electrophotographic printing for packaging by evaluating the recycling potential of electrophotographically printed paper using the INGEDE and the washing deinking method. In the first part of the study, typical office copy paper, containing up to 30% recycled fiber, was printed electrophotographically. In the second part of the study, the deinked pulp was then used to prepare the handsheets for deinking evaluation, paper analysis and printability analysis. The print quality of the recycled papers was highly encouraging, as the results were comparable and, in some cases, identical to those of papers manufactured from virgin fibers.

Keywords: recycling, electrophotography, deinking, flexography, printing, packaging

INTRODUCTION

The traditional method of producing paper from pulp derived from raw wood is unprofitable and unsustainable.[1] The UN environment program proposes many solutions and goals to help ensure sustainability on earth, including the 12th goal – Sustainable consumption and production. It aims to detach economic growth from environmental damage, boost resource efficiency, support the shift to low-carbon and green economies, and promote sustainable lifestyles. Recycling of paper is one of the ways to fulfill this goal.[2]

For more than 30 years, recycled paper has been sold in the market.[3] It is one of the best solutions to lessen environmental issues and waste generation. Recycling decreases the need for new raw materials and prevents the loss of potentially useful resources.[4] The Delft University of Technology has conducted a lot of research on the circular economy regarding packaging. The university is the founder of the 4R approach, which stands for "recycle, reuse, renew, and rethink." Recycling in this context refers to using waste packaging materials to create new packaging.[5] As the need for packaging board has expanded globally, a significant amount of secondary cellulose raw materials have been produced; these materials make up 25–40% of the municipal solid waste (MSW) that is disposed of in landfills and burned. Because of the production of harmful gases and contaminating leachate, these methods of disposal are not environmentally friendly. Forest resources can be preserved and other environmental effects can be reduced by recycling these fiber sources and using them as raw materials for new sustainable products.[6,7]

Paper recycling is a major priority for many nations worldwide. China, for instance, has set up a market-driven paper recycling system. More than several million tons of recovered paper are being recycled in the USA and Japan.[4] Most countries also have their own policies or laws on recycling, for example, Japan has a rigid law called Containers and Packaging Recycling Law to control the wastes in their country.[8] In Malaysia, the Solid Waste Management and Public Cleansing Corporation Act (SWCorp) was established by the government to support and ensure the successful implementation of the

National Solid Waste Management Policy.[9] Therefore, efficient use of waste paper might not only minimize the amount of MSW, but also help preserve and safeguard the environment.[7] Additionally, the current approaches to waste management are moving away from waste disposal towards recycling, reusing, and recovering. According to Bajpai, every ton of recycled paper that replaces a ton of virgin fiber results in a 100% decrease in wood use, a 33% reduction in wastewater, a 27% reduction in energy consumption, a 28% reduction in air particle emissions, and a 54% reduction in solid waste. This series of data shows the importance of waste paper recycling.[10] As a result, recycling waste paper is becoming more and more popular as a resource-saving and environmentally responsible option to producing pulp and paper.

However, sometimes recycling of recovered paper has a detrimental impact on the quality of the paper, for instance, recycled paper has a far lower quality than paper generated from virgin pulps because the fibers are shorter and have less tensile strength.[10] Paper fibers cannot be recycled continuously since they get damaged in the handling and recycling process. According to some researchers, fibers can be recycled up to seven times.[11] Every year, the paper industry uses 19 million tons of recycled paper to make containerboard, however, with every fiber reprocessing cycle, mechanical characteristics degrade because of the resistance of fiber to swelling when it is rewet after being dried.[12] Papers made from recycled fibers present changes in brightness over time and may turn yellow.[11] Some drawbacks in the quality of recycled paper are perceived by the user, such as its opacity (which affects strikethrough or see-through on double-sided printing), mechanical properties, and printer longevity. The impact of various paper properties that contribute to the print quality of the recycled paper is covered in this paper. An improvement in print quality would encourage more people to use recycled paper.[3] The majority of paper characteristics also affect how well paper prints electrophotographically. An increase in basis weight, brightness, caliper, density, hardwood fiber content (%), fluorescence, gloss, opacity and porosity would improve print quality, whereas an increase in Parker Print-Surf (PPS) roughness would have the opposite effect.[13]

Electrophotography is a dynamic technique that is frequently utilized in copiers, fax machines, and digital printers. It is an imaging technology that uses a photoreceptor, light source, electrostatic principles, and toner to print a digital file as an output. Despite numerous technological advancements throughout the years, the fundamental technique of electrophotography has essentially remained unaltered.[14] The color gamut of electrophotographic digital printing is influenced by a number of factors, such as the printer, the toner, and particularly, the characteristics of the paper (such as its whiteness, roughness, and gloss), which have an impact on the final color gamut and replication quality.[15]

The aim of this study is to perform electrophotographic printing on recycled paper using different deinking methods and analyze the optical, physical, and color variations of the resulting sheets after each recycling stage. Additionally, the properties and printing parameters of the printed papers are compared. Such studies are crucial for the paper, printing, and packaging industry, which is struggling from a lack of raw materials, as well as other financial and environmental issues.

EXPERIMENTAL

Sample

The sample used in this study consisted in recycled papers (electrophotographically printed papers containing up to 30% recycled fiber) with the basis weight of 80 gsm. The sample papers were printed with an HP LaserJet Printer (P3015) having HP proprietary dry toner. The content of the sample was printed as 11-point Sans Serif Type, single line spacing, as shown in Figure 1. Each recycled paper was printed on one side, so that the print area represented at least 50% ink coverage, and these prints were then deinked to prepare the recycled handsheets for flexo printing.[16]

Deinking conditions

The samples were deinked using two different deinking methods: the INGEDE (International Association of the Deinking Industry) method 11, which is a well-recognized method to evaluate the recyclability of waste paper in Europe,[17] and the washing method.

To perform the INGEDE method, the samples were aged in the oven for 72 hours at a constant temperature of 60 °C, disintegrated, and surfactants were added. The surfactants contained NaOH (0.6%), Na_2SiO_3 (1.8%), H_2O_2 (0.7%), and $C_{18}H_34O_2$ (0.8%). The recycled pulp slurry that was obtained was diluted to 0.8% Cy and deinked in a Voith flotation cell for 12 minutes.

In the washing method (WM), the sample was aged in the oven in the same way as in the INGEDE method (the sample was kept for 72 hours at a constant temperature of 60 °C). Thereafter, the sample was diluted to 0.8% Cy to form a pulp slurry. This pulp slurry and the displector deinking chemicals, which consisted of a combination water, sodium alkyl sulfate (SAS), specially denatured (SD) alcohol, sodium alkyl ethoxylate sulfate, and alkyl dimethyl amine oxide (ADAO), were introduced into the Voith flotation cell (Fig. 2) and the deinking process was performed for 12 min.

Figure 1: Electrophotographically printed papers

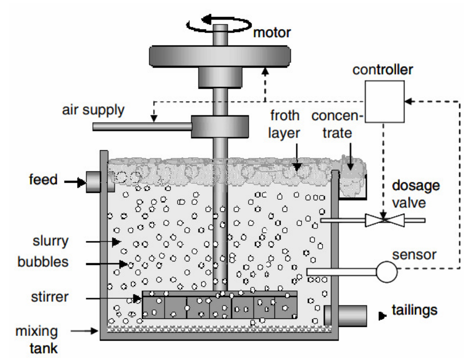


Figure 2: Schematic of deinking flotation cell[18]

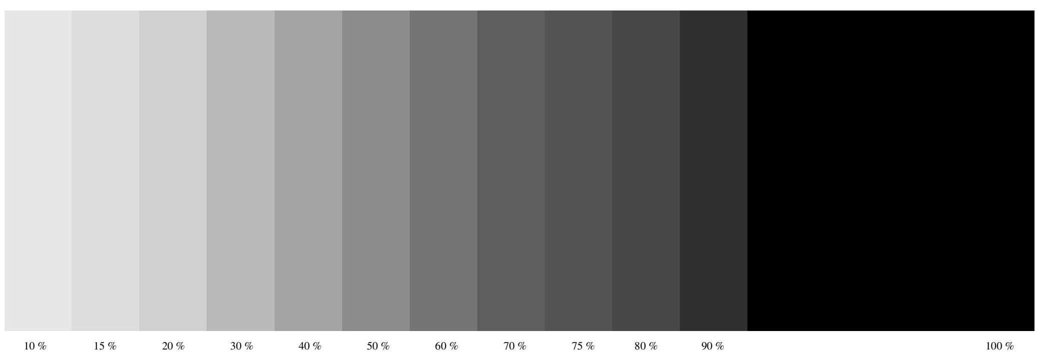


Figure 3: Digital file of flexo plate

Once the deinking process was complete, the pulp was taken out of the flotation cell and was weighed to determine the pulp yield. Sufficient handsheets were then prepared from the deinked pulp (by following the TAPPI Standard T205) and conditioned at 23 ºC, 50% relative humidity for 24 h. The handsheets were then evaluated for deinking efficiency, paper properties (mechanical, optical, and surface properties), and printability (color, optical, brightness, and print performance analysis). The samples were also tested for Parker Print-Surf (PPS) porosity (which actually measures air permeability[19]) by using the PPS tester at 1000 kPa clamping pressure (CP) with a soft backing. Thickness in micron was determined using a TMI Micrometer. Roughness in micron was assessed using a PPS ME-90 (1000 kPa, soft backing) based on TAPPI T555-OM-99. Gloss percent was measured at 75º using a Novo-Gloss™ Glossmeter based on TAPPI standard T480-OM-99. CIE L*a*b* color values were measured using an X-rite EXact device in M1 mode, and brightness – with a Technidyne Brightimeter Micro S-5 based on TAPPI Standard T452-OM-98 (457 nm light). In the end, all the experimental values obtained for the handsheets were compared with those for the base commercial paper.

Printing conditions

The test samples were printed using a Flexiproof 100 device with cyan commercial ink, provided by Wikoff Color Corporation. For printing, a flexible photopolymer printing plate was used (size 260 x 90 mm, thickness 1.7 mm and screen frequency 39.37 l/cm (100 lpi)); the digital file shown in Figure 3 was used to print. Prints were carried out at 40 m/min printing speed, 45 units pressure between the anilox roller and the plate cylinder, and 50 units pressure of between the plate cylinder and the impression cylinder. An anilox cylinder with screen frequency of 200.6 l/cm

(510 lpi) was used to meter the ink to the plate. The capacity of its ink-cells was 5 cm^3/m^2.[20] The values of print density, print contrast, dot gain and CIE L*a*b* values were measured with an X-rite EXact device, using M1 mode, D/50 light source under an observation angle of 2° after printing. For calculating delta gloss, the unprinted and printed gloss values were measured at 60º using a BYK micro-gloss meter based on TAPPI standard T480-OM-99.[21] Dot roundness was determined using Paxit software.

In the study, the following abbreviations were used: BP – for base paper, WMUPD – for deinked unprinted paper produced using the washing method, WMPUD – for undeinked printed paper produced using the washing method, WMPD – for deinked printed paper produced using the washing method, IMUPD – for deinked unprinted paper produced using the INGEDE method 11, IMPUD – for undeinked printed paper produced using the INGEDE method 11, and IMPD – for deinked printed paper produced using the INGEDE method 11. These abbreviations are used in the tables and figures.

RESULTS AND DISCUSSION

Physical and optical properties of paper

Table 1 presents the physical properties of the handsheets obtained by using the washing method and the INGEDE method. The shortening in the fiber lengths due to the fragmentation after deinking of the long fiber ratio present in the base paper caused an increase in the PPS porosity value. The reason for the increase in the porosity values for the INGEDE method, compared to the washing method, is that the chemicals used in the ink removal process increased the rate of fragmentation in the fibers. In addition, the toner particles, which could not be removed from the environment as a result of deinking, closed the existing gaps between the fibers, resulting in a decrease in the porosity values. It is seen that the surface roughness values of the handsheets deinked by the INGEDE method are slightly lower than those of the handsheets subjected to the washing method. If the handsheets obtained are passed through a calendering process, there will be an increase in the surface smoothness of the handsheets for both deinking methods.

The tensile index values of the handsheets (for both the washing method and the INGEDE method) were lower than those of BP, because of the damage produced to the fibers. However, when the burst indices are compared, the values corresponding to the INGEDE method are slightly lower than those of the washing method. In both methods, it is seen that the burst index increases in PD, compared to PUD. This increase indicates a positive result of the removal of pigment particles from the environment. Regarding the tear index, it is seen that there is an increase in the strength values after deinking. The choice of the deinking method did not lead to significant differences in the tensile index. It has been determined that the resistance properties of the papers produced using the washing method are slightly higher than those of the papers produced using the INGEDE method (Table 2).

Table 1
Physical properties of handsheets

Test sample	Thickness (µm)	Std	Roughness (µm)	Std	PPS porosity (mL/min)	Std	Permeability (μm^2)	Std
BP	93.98	NA	6.67	0.22	954.64	29.21	0.00438	0.00013
WMUPD	125.98	2.27	8.55	0.24	1457.80	76.38	0.00897	0.00047
WMPUD	138.22	5.99	8.83	0.16	2702.00	63.91	0.01824	0.00043
WMPD	113.03	1.47	8.32	0.05	874.04	73.18	0.00482	0.00040
IMUPD	142.04	4.66	8.13	0.07	1726.60	51.07	0.01198	0.00035
IMPUD	149.50	5.20	8.36	0.11	4238.00	95.58	0.03094	0.00069
IMPD	137.67	4.89	8.25	0.06	1609.00	79.22	0.01082	0.00053

Table 2
Grammage and strength comparison of handsheets

Test sample	Grammage (g/m^2)	Std	Tensile index (N.m/g)	Std	Burst index ($kPa.m^2/g$)	Std	Tear index ($mN.m^2/g$)	Std
BP	80.00	NA	0.10	0.002	0.35	0.01	0.80	NA
WMUPD	79.37	1.50	0.05	0.002	0.25	0.01	0.54	0.06
WMPUD	79.40	1.61	0.05	0.002	0.24	0.01	0.52	0.05

WMPD	79.27	1.38	0.05	0.001	0.25	0.02	0.61	0.00
IMUPD	79.00	1.25	0.04	0.002	0.19	0.02	0.53	0.05
IMPUD	79.80	1.67	0.03	0.004	0.16	0.01	0.42	0.04
IMPD	78.47	1.76	0.04	0.005	0.22	0.01	0.59	0.05

Table 3
Optical properties of handsheets

Test sample	Brightness (%)	Std	Opacity (%)	Std	Paper gloss 75°	Std
BP	80.86	0.27	90.14	0.17	6.92	0.08
WMUPD	89.20	0.16	90.64	0.48	6.34	0.15
WMPUD	63.16	0.39	97.62	0.19	5.98	0.05
WMPD	76.65	1.65	92.34	0.47	6.52	0.16
IMUPD	84.56	0.65	90.92	0.99	6.22	0.16
IMPUD	66.49	1.02	97.34	0.20	5.74	0.06
IMPD	79.04	1.17	92.24	0.35	6.36	0.09

Table 4
CIE L*a*b* color values of handsheets

Test sample	L*	Std	a*	Std	b*	Std
BP	94.06	0.09	2.01	0.03	-8.11	0.19
WMUPD	94.66	0.04	1.63	0.04	-6.30	0.08
WMPUD	84.09	0.43	1.12	0.06	-4.76	0.05
WMPD	94.72	0.18	1.59	0.07	-6.13	0.08
IMUPD	95.35	0.19	1.30	0.07	-5.13	0.26
IMPUD	85.57	0.10	1.11	0.01	-5.24	0.03
IMPD	92.85	0.11	1.30	0.06	-4.49	0.21

The data in Table 3 reveal that the brightness values of UPD handsheets are higher than those of BP for both deinking methods used. This increase is due to the removal of OBA present in the environment during the deinking process. It was determined that the brightness values of PD and UPD handsheets were affected positively by the INGEDE method, compared to the washing method, and the removal of toner particles from the pulp increased the brightness values for both methods. On the other hand, the increasing amount of toner particles in the pulp also increased the opacity values. It was determined that the washing method increased the brightness of the handsheets, compared to INGEDE, and there was an increase in the gloss values in direct proportion to the toner particles removed from the pulp.

The CIE L*a*b* color values of the original copy paper and handsheets are shown in Table 4. By keeping constant the CIE L*a*b* color values of the original copy paper, the paper color difference value (ΔE_{00}) was calculated using Equation (1):

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

where R_T = a hue rotation term; K_L, K_C and K_H = parametric factors; L*C*h = compensation for neutral colors, SL = compensation for lightness, SC = compensation for chroma, SH = compensation for hue.

According to these calculated values, ΔE_{00} of 1.46 was obtained for WMUPD, ΔE_{00} 6.88 for WMPUD, ΔE_{00} 1.60 for WMPD, ΔE_{00} 2.52 for IMUPD, ΔE_{00} 5.85 for IMPUD, ΔE_{00} 2.99 for IMPD. These values show that the handsheets deinked using the WM have the closest color tone to the color values of the BP. This obtained color difference indicates that OBA in the recycling pulp was better removed by INGEDE, compared to the washing method. In order to calculate the deinking evaluation factor (DEMLab), the color values in the CIE L*a*b* color system of unprinted paper and printed handsheets are used. For the calculation of the deinkability factor (DEMf) value, the brightness values are used. The DEMLab and DEMf deinkability factors are given in Equations (2) and (3).

The deinking evaluation factor (DEMLab) was calculated using Equation (2):[22,23]

$$DEMLab = \left(1 - \frac{\sqrt{(L^*_{US} - L^*_{DS})^2 + (a^*_{US} - a^*_{DS})^2 + (b^*_{US} - b^*_{DS})^2}}{\sqrt{(L^*_{US} - L^*_{BS})^2 + (a^*_{US} - a^*_{BS})^2 + (b^*_{US} - b^*_{BS})^2}}\right) 100[\%] \quad (2)$$

where US – unprinted deinked pulp, BS – printed undeinked pulp, DS – deinked pulp.

The deinkability factor (DEMf) was calculated using Equation (3):[17]

$$DEMf = \frac{Brightness_{DS} - Brightness_{BS}}{Brightness_{US} - Brightness_{BS}} \times 100[\%] \quad (3)$$

Table 5
Deinkability efficiency properties of handsheets

Test samples	Deinkability	
	DEMLab (%)	DEMf (%)
WM	98.53	51.80
IM	74.36	69.45

WM – washing method, IM – INGEDE method

The deinkability factors are in the range of 0-100%, values close to 100% indicate excellent ink removal, and values close to 0% indicate poor deinking. The deinkability efficiencies of the prepared handsheets are given in Table 5. These values show that higher efficiency was obtained by the washing method than by the INGEDE method. However, it has been determined that INGEDE is more efficient than the washing method in terms of brightness.

VERITY IA Light and Dark Dirt 3.4.0 software was used to determine the dirt count in undeinked and deinked handsheet papers. For use of the software, handsheets were first scanned at 1200 ppi using the Epson Perfection V750 Pro scanner. The minimum speck area settings are defined as 0.02 (T563) and 0.007 mm^2. The other dirt analysis settings are: shape (12.57-300, 12.57 is perfect circle); luminance (0-190); and threshold is the background mode minus 30.[24]

The ink elimination factor (IE_{ERIC}) was calculated using Equation (4):

$$IE_{ERIC} = \frac{ERIC_{UP} - ERIC_{DP}}{ERIC_{UP} - ERIC_{UNPR}} x100 \quad (4)$$

where UP – undeinked pulp, DP – deinked pulp, UNPR – unprinted pulp.

The obtained dirt area and ink elimination factors are given in Table 6. When comparing unprinted pulp, the dirt area was slightly higher for the WM than for IM. However, the dirt areas of undeinked and deinked pulps using WM were lower than those for IM. When the ink elimination factors were examined, WM showed better results by 1% compared to IM. In the images given in Figure 4, the difference between WM and IM is seen clearly.

Print density

Density represents the ability of ink to absorb light. Thus, measuring the light reflected from the ink printed surface gives the print density. The resulting value indicates how dark the resulting color appears after printing. A thick ink layer indicates that the ink has a strong ability to absorb light. The higher this value, the higher the density value.[25,26]

Table 6
Visible dirt area and ink elimination factors of test samples

Test samples	Dirt area of			IE_{ERIC}
	Unprinted pulp	Undeinked pulp	Deinked pulp	(%)
WM	192	51655	3795	93
IM	130	59961	4862	92

As may be seen in Figure 5, the BP density value is higher than those for both deinking methods. This is due to the surface roughness and porosity of BP being lower than those of produced handsheets. The lower density value of WMPUD is due to the higher surface roughness, compared to those of the other produced handsheets. Since the amount of pigment remaining on the surface will be higher in a substrate with a high surface smoothness and a low air permeability structure, the resulting print density value will be higher. It was determined that the deinking method did not have a significant impact on the print density value.

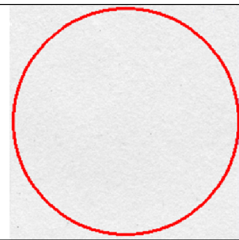
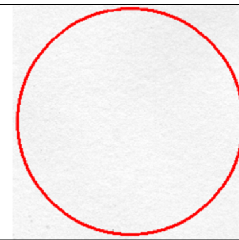
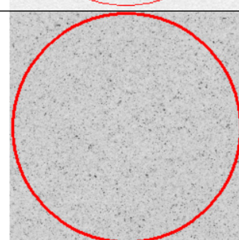
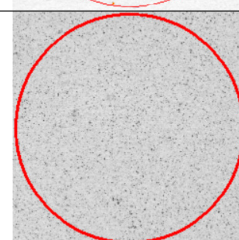
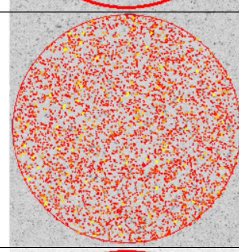
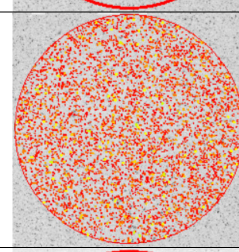
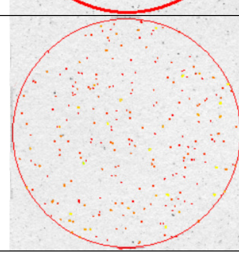
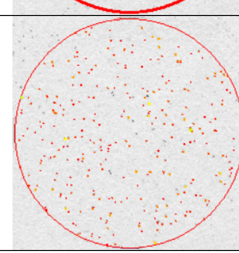
Test samples	WM	IM
Unprinted pulp		
Dirt area of unprinted pulp		
Undeinked pulp		
Dirt area of undeinked pulp		
Deinked pulp		
Dirt area of deinked pulp		

Figure 4: Dirt area of test samples

Print contrast

Print contrast is defined as the capacity of image detail obtained in the shadow regions of images printed on a printing system. The print contrast with the lowest dot gain at the highest ink density is the ideal value.[27] The ratio of the difference between the density of the solid print area and the printed shadow tint area to the solid density gives the print contrast value and this ratio is expressed as a percentage.[28] The values presented in Figure 3 were obtained by comparing the solid and 75 percent dot density values. With the print contrast value, the better ink density of the flexo plate can be controlled. In this, it is important for the flexo plate to receive the right amount of ink from the anilox roll during printing.

Figure 6 shows that the toner particles in the undeinked handsheets have reduced the print contrast value. The removal of toner particles from the pulp increased the print contrast. The print contrast value obtained after deinking is higher than that of the BP. The different deinking methods used made a significant impact on the print contrast.

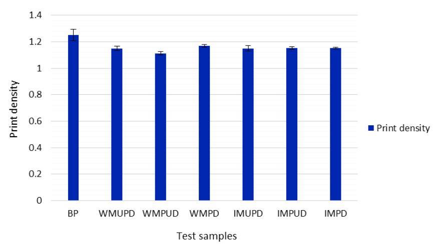


Figure 5: Print density of handsheets

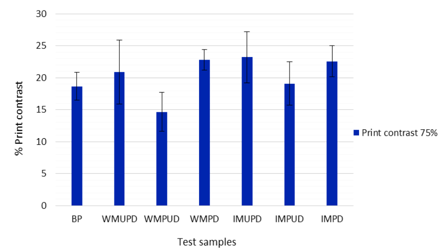


Figure 6: Print contrast of handsheets

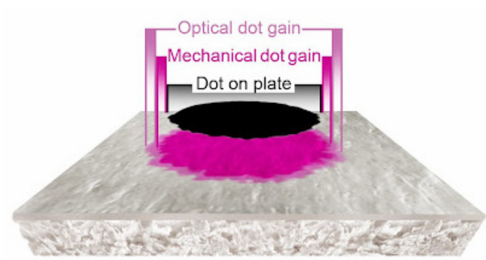


Figure 7: Components of tone value increase[33]

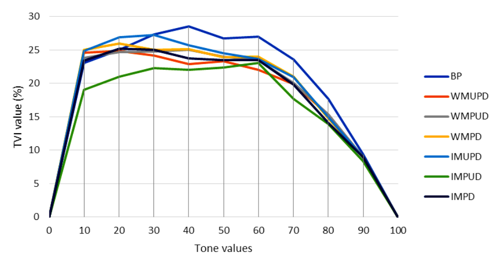


Figure 8: Print tone value increase of handsheets

Tone value increase (TVI)

Tone values are used to obtain colors in multi-colored works. Although these values are at a certain level during the design, they exhibit an increase as a result of the printing process. This is called tone value increase (TVI) in the printing industry.[29,30] For this reason, while designing the file to be printed, the necessary tone value selections should be made by keeping the TVI in mind. During this selection, elements, such as paper type, printing type, the ink to be used *etc*., must be taken into account.[31]

Dot gain or TVI has two basic components (Fig. 7): the first is the mechanical dot gain, which occurs as a result of the physical spreading of the ink under pressure, and the other is the optical dot gain, which is formed by the shadow of the light in the substrate around the dot.[32]

TVI values close to each other were obtained in the handsheets obtained by both methods, except IMPUD, which showed the lowest TVI values. The smoothness of the surface is very important in obtaining dots with sharp lines and without ink loss. If the handsheets are passed through the calendering process, the surface smoothness will increase and quality dots can be obtained (Fig. 8).

Print chroma

The degree of departure of a color from a neutral color of the same value is called "chroma".[34] The chroma value gives information about the saturation of that color. Low chroma implies weakly saturated color, while high chroma stands for highly saturated color. The units of chroma are dimensionless.[35,36]

Figure 9 shows that the print chroma values of the handsheets obtained after deinking increased for both deinking methods. It is seen that the print chroma value of the handsheets obtained as a result of deinking by the washing method is higher. Therefore, higher saturation prints can be obtained.

Table 7 illustrates the CIE L*a*b* color values of printed handsheets. The values of $\Delta E_{00\ Print}$ was calculated by Equation (1). According to these calculated values, ΔE_{00} of 5.16 was achieved in WMUPD, ΔE_{00} 2.62 – in WMPUD, ΔE_{00} 7.49 – in WMPD, ΔE_{00} 5.74 – in IMUPD, ΔE_{00} 1.68 – IMPUD, and ΔE_{00} 8.66 – in IMPD. These values reveal that the printed handsheets from undeinked pulp have the lowest $\Delta E_{00\ Print}$, because both methods include OBA to some extent. Thus, the print color is the closest color tone to the color values of the BP. IM yields better $\Delta E_{00\ Print}$ than WM in the case of undeinked printed papers.

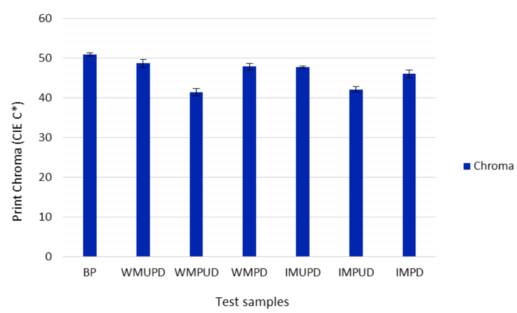


Figure 9: Print chroma of handsheets

Table 7
CIE L*a*b* color values of printed handsheets

Test sample	L*	Std	a*	Std	b*	Std	$\Delta E_{00\ Print}$	Std
BP	39.69	0.98	-6.99	1.01	-50.42	0.30	-	-
WMUPD	45.32	1.46	-10.36	0.46	-47.51	1.08	5.16	1.14
WMPUD	44.71	0.38	-9.24	0.06	-40.28	0.97	2.62	1.58
WMPD	45.96	1.43	-10.30	0.20	-46.69	0.88	7.49	1.33
IMUPD	46.72	0.41	-10.85	0.09	-46.42	0.25	5.74	1.47
IMPUD	46.02	0.38	-9.66	0.66	-40.95	0.54	1.68	0.65
IMPD	46.33	0.88	-10.52	0.26	-44.74	0.99	8.66	1.29

CONCLUSION

The recycling, which was conducted on typical electrophotographic office copy paper, had a positive influence on selected optical, mechanical, and printing properties of the paper. The findings revealed that the roughness was the highest in the WMPUD handsheets, while the thickness, PPS porosity, and permeability were the highest in the IMPUD handsheets. For the samples studied, the tensile index, bursting index, and tearing index remained the highest for the BP. Brightness and opacity were the highest in WMUPD, while gloss remained the highest for the BP. As regards the CIE L*a*b* color values, IMUPD exhibited the highest value of L*, the BP had the highest value of a*, and IMPD – the highest value of b*. Higher DEMLab% was achieved by the washing method, while the INGEDE method led to higher DEMf%. When comparing the CIE L*a*b* color values of printed handsheets, the L* value was the highest for IMPUD, BP showed the highest a* value, and WMPUD – the highest b* value, while ΔE_{00} print was observed to be the highest in WMPD. The differences between 100% recycled papers and papers made of virgin fibres were extremely small, as 100% recycled papers achieved high print quality. Based on the findings of this study regarding print quality, 100% recycled sheets might completely replace papers made from virgin fibers for use in electrophotographic printing in regular office settings, as well as in flexography in packaging. The variations in flexo printing parameters are totally explainable in terms of residual toner or ink.

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