A Comparison of Conventional and New Technology Gravure Cylinders In Terms of Image Quality

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Abstract

Gravure is losing package printing market share to Flexo in North America. Closing the cost gap between flexo and gravure is a prerequisite to regaining market share. This could be accomplished by adopting new cylinder technologies that reduce the cost of cylinder preparation and the size of cylinder inventories. This study examined one such technology, RotoHybrid Cylinders. RotoHybrid is new to the gravure industry and has just entered beta testing. Gravure printers would like to understand how RotoHybrid and Conventional Chrome cylinders compare in terms of ability to print images. This research assessed image quality differences between conventional Chrome cylinders and RotoHybrid cylinders (HCR Type 1) when cylinders are new. For this research, image quality was assessed on the basis of density and the visual quality of ISO images.

The print trial used Chrome and HCR Type 1 cylinders (electromechanically engraved copper on a steel base protected by a Hybrid Chrome Replacement coating). The result of the trial demonstrated that RotoHybrid cylinders outperform conventional Chrome cylinders in terms of density and dot quality. Based on these results, RotoHybrid cylinders could create an opportunity for gravure printers to regain market share in package printing.

Background

The Gravure industry in North America has been declining and losing market share to Flexo in package printing for several decades (Gravure & Its Markets, 2018). It is understood from Karl Bardin's statement (Kozak, 2004), a significant factor affecting this decline is the cost difference between preparing and engraving

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cylinders versus making and mounting flexo plates. Today, leading flexo printers prepare and mount flexo plates in their printing plants where cost is reduced by using shared resources. In contrast, gravure cylinder preparation and engraving is commonly outsourced to a third- party supplier. Hence, gravure has to bear the added burden of the supplier's infrastructure cost, transport cost, and profit margin (Luman, 2017; Ellis, 2017).

Current technology gravure cylinders have two layers of metal on a steel base: soft engravable copper and hard protective chrome. The protective functionality of chrome is required to achieve an economically acceptable print life and high quality reproduction of images (Gravure Association of America, & Gravure Education Foundation, 2003, pp. 204-205). However, the chrome bath used in electroplating is toxic and environmentally hazardous to earth soil, air and water (Health Effects Notebook for Hazardous Air Pollutants, 2017; National Institute for Occupational Safety and Health, 1975; Chromic Acid, n.d.). The chrome electroplating process is not banned by the government, but it is heavily regulated (Environmental Protection Agency, 2012; Chromium Electroplating: National Emission Standards for Hazardous Air Pollutants, 2016; United States Department of Labor, n.d.). Printers are reluctant to accept this regulatory burden because it makes it difficult to run their plants efficiently. This regulatory burden is heavy enough to convince most printers not to bring current technology cylinder preparation and engraving in-house (Friedman, 1998).

Closing the cost gap between flexo and gravure depends on adopting in-plant cylinder production. Eliminating the need for chrome in gravure cylinder preparation requires new technology. Such technology would reduce the burden of environmental regulation and clears the path for printers to bring the cylinder production into the plant.

Today, chromeless gravure cylinders are being developed by RotoHybrid (a research company developing new gravure cylinder technology). RotoHybrid's chromeless cylinders are new to the gravure industry and have just entered beta testing. Gravure printers would like to understand difference between the RotoHybrid Cylinders and Conventional gravure cylinders in terms of image quality.

Theoretical Basis

In this research, printed ink density is used as one measure of image quality. For precise density measurement of ink alone, the density of the substrate has to be subtracted from the combined density of the ink and paper. This can be accomplished by calculating relative density as shown in Equation 1 (Williams, 2007).

$$D_{rel} = D_{i+p\ (abs)} - D_{p\ (abs)} \qquad (1)$$

where Drel =Relative Density

Di+p (abs) = Absolute density of ink and paper

Dp (abs) = Absolute density of paper

Literature Review

Hybrid Chrome Replacement (HCR) technology was developed by RotoHybrid to replace chrome plating. The Hybrid Chrome Replacement (HCR) coating process has its foundation in Diamond-Like Carbon (DLC) formed from a material containing carbon atoms as a major constituent and a trace amount of hydrogen atoms (RotoHybrid Coatings, n.d; Hybrid-Cylinders, 2017, para. 5; U.S. Patent No. 8,691,386, 2014).

DLC combines the properties of graphite and diamond. DLC films made with a high concentration of sp2 bonded carbon atoms behave more like graphite during tribological (friction) tests. DLC films made with high concentrations of sp3 bonded carbon atoms behave are more like diamond, are super hard, and perform impressively in tribological environments (Erdemir & Donnet, 2006). Prior research indicates that Plasma Enhanced Chemical Vapor Deposition (PECVD) is commonly used (Vetter, 2014; Singh & Jatti, 2015) for coating DLC on the metal surfaces.

Methodology

The methodology consists of the steps required to generate samples for measurement followed by the steps required to analyze these samples and draw conclusions. The methodology is divided in to nine steps which are outlined in the flowchart shown below (see Figure 1).

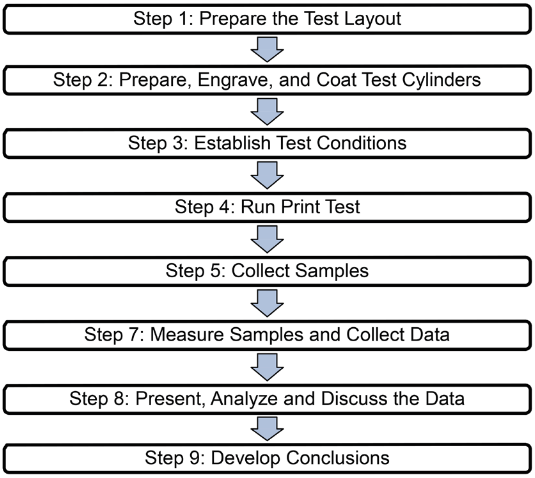


Figure 1. *Flowchart showing overview of steps involved in the methodology*

The four color test layout designed for the print test includes one Step Wedge and ISO Image. This layout was identically engraved on Chrome and HCR Type 1 cylinders. Subsequently, the cylinders are used on the Mondi Production Press to print on the plastic substrate at a standard press conditions using solvent based ink. The print samples collected were measured using a Techkon SpectroDens to generate density data.

Results

This section discusses the analysis of density and image quality. It first discusses the quantitative density data generated by measurement of the print samples. Density data is presented graphically and statistically analyzed. For statistical analysis, T-tests for equality of means. The second section presents and discusses qualitative data generated from a visual assessment of ISO images.

Quantitative Density Data. Figures 2, 3, 4, and 5 compare Chrome and HCR

Type 1 print density data measured on production press prints. For each print, the data source used is a Tone Wedge. Examination of Figure 2 shows that the HCR Type 1 print densities using black ink are higher than the corresponding Chrome print densities. This observation is also true for the yellow, magenta, and cyan data (see Figures 3 - 5).

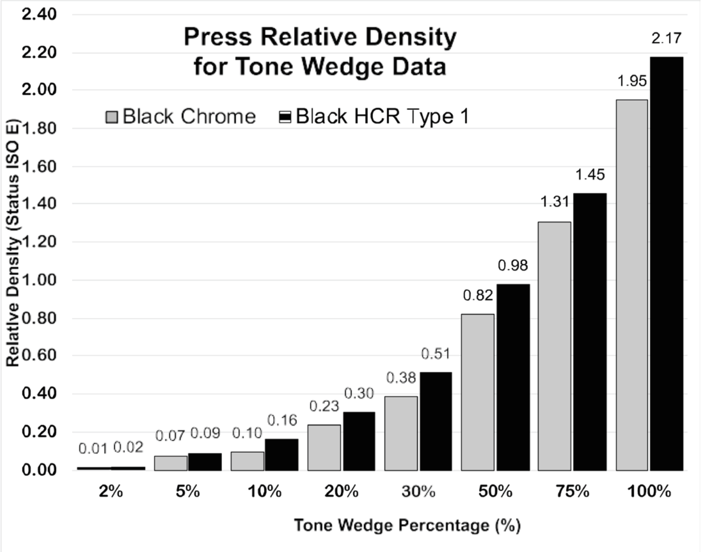


Figure 2. *Black Relative Densities for Tone Wedge Data. The bar chart summarizes average data for 20 Tone Wedge measurements obtained from Mondi Production Press samples.*

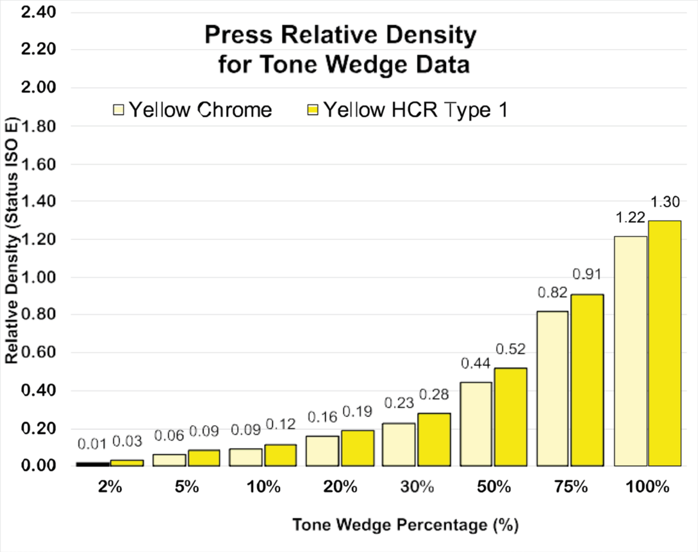


Figure 3. *Yellow Relative Densities for Tone Wedge Data. The bar chart summarizes average data for 20 Tone Wedge measurements obtained from Mondi Production Press samples.*

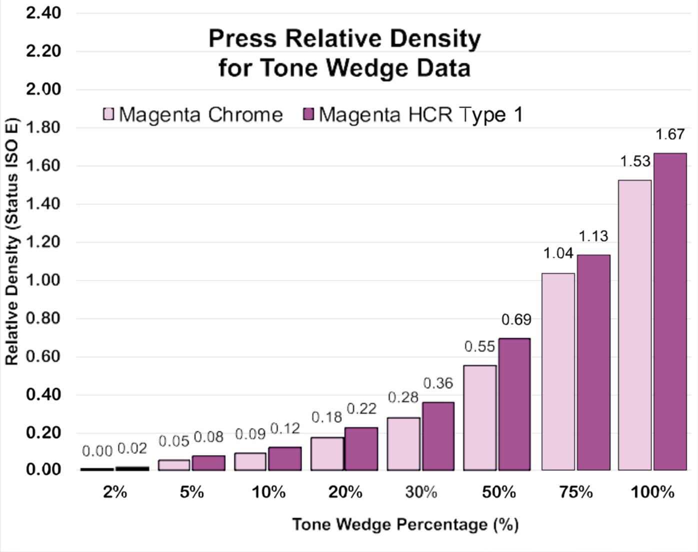


Figure 4. *Magenta Relative Densities for Tone Wedge Data. The bar chart summarizes average data for 20 Tone Wedge measurements obtained from Mondi Production Press samples.*

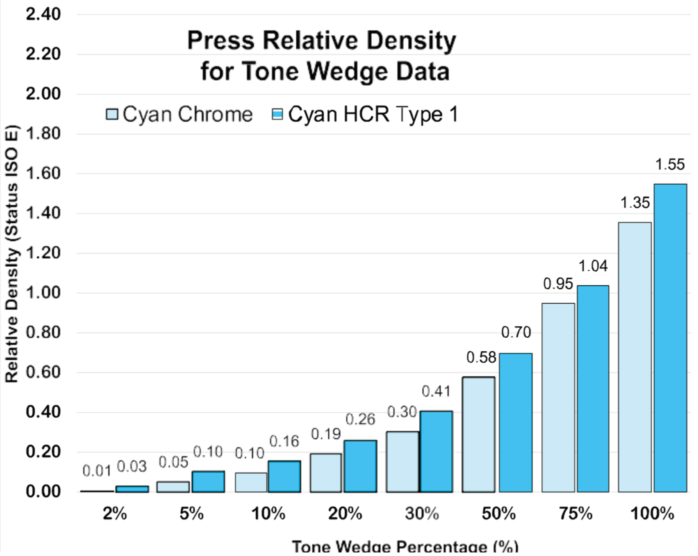
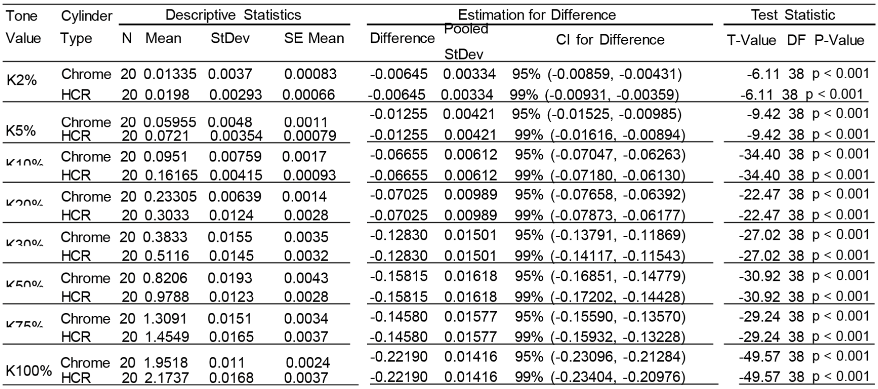


Figure 5. *Cyan Relative Densities for Tone Wedge Data. The bar chart summarizes average data for 20 Tone Wedge measurements obtained from Mondi Production Press samples.*

The consistently higher HCR Type 1 print densities observed (compared to Chrome) warrant statistical analysis to investigate the significance of this observation. Statistical analysis of black, yellow, magenta and cyan density data from press prints using Chrome and HCR Type 1 Cylinders are shown in Tables 1 to 4. The results reveal that the difference is significant at $p < 0.001$ for all tone percentages.



Tone	Cylinder	Descriptive Statistics				Estimation for Difference			Test Statistic		
Value	Type	N	Mean	StDev	SE Mean	Difference	Pooled StDev	CI for Difference	T-Value	DF	P-Value
K2%	Chrome	20	0.01335	0.0037	0.00083	-0.00645	0.00334	95% (-0.00859, -0.00431)	-6.11	38	p < 0.001
	HCR	20	0.0198	0.00293	0.00066	-0.00645	0.00334	99% (-0.00931, -0.00359)	-6.11	38	p < 0.001
K5%	Chrome	20	0.05955	0.0048	0.0011	-0.01255	0.00421	95% (-0.01525, -0.00985)	-9.42	38	p < 0.001
	HCR	20	0.0721	0.00354	0.00079	-0.01255	0.00421	99% (-0.01616, -0.00894)	-9.42	38	p < 0.001
K10%	Chrome	20	0.0951	0.00759	0.0017	-0.06655	0.00612	95% (-0.07047, -0.06263)	-34.40	38	p < 0.001
	HCR	20	0.16165	0.00415	0.00093	-0.06655	0.00612	99% (-0.07180, -0.06130)	-34.40	38	p < 0.001
K20%	Chrome	20	0.23305	0.00639	0.0014	-0.07025	0.00989	95% (-0.07658, -0.06392)	-22.47	38	p < 0.001
	HCR	20	0.3033	0.0124	0.0028	-0.07025	0.00989	99% (-0.07873, -0.06177)	-22.47	38	p < 0.001
K30%	Chrome	20	0.3833	0.0155	0.0035	-0.12830	0.01501	95% (-0.13791, -0.11869)	-27.02	38	p < 0.001
	HCR	20	0.5116	0.0145	0.0032	-0.12830	0.01501	99% (-0.14117, -0.11543)	-27.02	38	p < 0.001
K50%	Chrome	20	0.8206	0.0193	0.0043	-0.15815	0.01618	95% (-0.16851, -0.14779)	-30.92	38	p < 0.001
	HCR	20	0.9788	0.0123	0.0028	-0.15815	0.01618	99% (-0.17202, -0.14428)	-30.92	38	p < 0.001
K75%	Chrome	20	1.3091	0.0151	0.0034	-0.14580	0.01577	95% (-0.15590, -0.13570)	-29.24	38	p < 0.001
	HCR	20	1.4549	0.0165	0.0037	-0.14580	0.01577	99% (-0.15932, -0.13228)	-29.24	38	p < 0.001
K100%	Chrome	20	1.9518	0.011	0.0024	-0.22190	0.01416	95% (-0.23096, -0.21284)	-49.57	38	p < 0.001
	HCR	20	2.1737	0.0168	0.0037	-0.22190	0.01416	99% (-0.23404, -0.20976)	-49.57	38	p < 0.001

Table 1: *Statistical Analysis of Black Relative Densities for Tone Wedge Data from Press Prints*

Tone	Cylinder	Descriptive Statistics				Estimation for Difference			Test Statistic		
Value	Type	N	Mean	StDev	SE Mean	Difference	Pooled StDev	CI for Difference	T-Value	DF	P-Value
M2%	Chrome	20	0.0045	0.000946	0.00021	-0.01370	0.00113	95% (-0.014421, -0.012979)	-38.47	38	$p < 0.001$
	HCR	20	0.0182	0.00128	0.00029	-0.01370	0.00113	99% (-0.014666, -0.012734)	-38.47	38	$p < 0.001$
M5%	Chrome	20	0.04295	0.00167	0.00037	-0.02090	0.00143	95% (-0.021814, -0.019986)	-46.28	38	$p < 0.001$
	HCR	20	0.06385	0.00114	0.00025	-0.02090	0.00143	99% (-0.022125, -0.019675)	-46.28	38	$p < 0.001$
M10%	Chrome	20	0.0933	0.00247	0.00055	-0.03155	0.00219	95% (-0.032954, -0.030146)	-45.49	38	$p < 0.001$
	HCR	20	0.12485	0.00187	0.00042	-0.03155	0.00219	99% (-0.033430, -0.029670)	-45.49	38	$p < 0.001$
M20%	Chrome	20	0.17775	0.00529	0.0012	-0.04710	0.00428	95% (-0.04984, -0.04436)	-34.79	38	$p < 0.001$
	HCR	20	0.22485	0.00294	0.00066	-0.04710	0.00428	99% (-0.05077, -0.04343)	-34.79	38	$p < 0.001$
M30%	Chrome	20	0.28095	0.00577	0.0013	-0.07625	0.00525	95% (-0.07961, -0.07289)	-45.91	38	$p < 0.001$
	HCR	20	0.3572	0.00467	0.001	-0.07625	0.00525	99% (-0.08075, -0.07175)	-45.91	38	$p < 0.001$
M50%	Chrome	20	0.5498	0.0111	0.0025	-0.14500	0.00881	95% (-0.15064, -0.13936)	-52.05	38	$p < 0.001$
	HCR	20	0.69485	0.00571	0.0013	-0.14500	0.00881	99% (-0.15255, -0.13745)	-52.05	38	$p < 0.001$
M75%	Chrome	20	1.0378	0.0141	0.0032	-0.09345	0.01096	95% (-0.10047, -0.08643)	-26.96	38	$p < 0.001$
	HCR	20	1.1312	0.00635	0.0014	-0.09345	0.01096	99% (-0.10285, -0.08405)	-26.96	38	$p < 0.001$
M100%	Chrome	20	1.5264	0.0129	0.0029	-0.13920	0.01111	95% (-0.14631, -0.13209)	-39.62	38	$p < 0.001$
	HCR	20	1.6656	0.00901	0.002	-0.13920	0.01111	99% (-0.14873, -0.12967)	-39.62	38	$p < 0.001$

Table 2: *Statistical Analysis of Yellow Relative Densities for Tone Wedge Data from Press Prints*

Tone	Cylinder	Descriptive Statistics				Estimation for Difference			Test Statistic		
Value	Type	N	Mean	StDev	SE Mean	Difference	Pooled StDev	CI for Difference	T-Value	DF	P-Value
C2%	Chrome	20	0.0073	0.00184	0.00041	-0.02065	0.00163	95% (-0.021694, -0.019606)	-40.02	38	$p < 0.001$
	HCR	20	0.02795	0.00139	0.00031	-0.02065	0.00163	99% (-0.022049, -0.019251)	-40.02	38	$p < 0.001$
C5%	Chrome	20	0.0387	0.00192	0.00043	-0.04300	0.00190	95% (-0.044213, -0.041787)	-71.77	38	$p < 0.001$
	HCR	20	0.0817	0.00187	0.00042	-0.04300	0.00190	99% (-0.044625, -0.041375)	-71.77	38	$p < 0.001$
C10%	Chrome	20	0.09775	0.00271	0.00061	-0.05870	0.00267	95% (-0.060409, -0.056991)	-69.55	38	$p < 0.001$
	HCR	20	0.15645	0.00263	0.00059	-0.05870	0.00267	99% (-0.060989, -0.056411)	-69.55	38	$p < 0.001$
C20%	Chrome	20	0.1896	0.00607	0.0014	-0.07305	0.00520	95% (-0.07638, -0.06972)	-44.38	38	$p < 0.001$
	HCR	20	0.26265	0.00416	0.00093	-0.07305	0.00520	99% (-0.07751, -0.06859)	-44.38	38	$p < 0.001$
C30%	Chrome	20	0.3006	0.00634	0.0014	-0.10595	0.00621	95% (-0.10993, -0.10197)	-53.91	38	$p < 0.001$
	HCR	20	0.40655	0.00609	0.0014	-0.10595	0.00621	99% (-0.11128, -0.10062)	-53.91	38	$p < 0.001$
C50%	Chrome	20	0.57915	0.00924	0.0021	-0.12120	0.00907	95% (-0.12701, -0.11539)	-42.25	38	$p < 0.001$
	HCR	20	0.70035	0.0089	0.002	-0.12120	0.00907	99% (-0.12898, -0.11342)	-42.25	38	$p < 0.001$
C75%	Chrome	20	0.9479	0.0101	0.0023	-0.09090	0.00899	95% (-0.09666, -0.08514)	-31.96	38	$p < 0.001$
	HCR	20	1.0388	0.00769	0.0017	-0.09090	0.00899	99% (-0.09861, -0.08319)	-31.96	38	$p < 0.001$
C100%	Chrome	20	1.3547	0.0172	0.0039	-0.19500	0.01430	95% (-0.20416, -0.18584)	-43.11	38	$p < 0.001$
	HCR	20	1.5497	0.0106	0.0024	-0.19500	0.01430	99% (-0.20726, -0.18274)	-43.11	38	$p < 0.001$

Table 3: *Statistical Analysis of Magenta Relative Densities for Tone Wedge Data from Press Prints*

Tone	Cylinder	Descriptive Statistics				Estimation for Difference			Test Statistic		
Value	Type	N	Mean	StDev	SE Mean	Difference	Pooled StDev	CI for Difference	T-Value	DF	P-Value
Y2%	Chrome	20	0.01465	0.00109	0.00024	-0.01680	0.00177	95% (-0.017935, -0.015665)	-29.96	38	$p < 0.001$
	HCR	20	0.03145	0.00226	0.00051	-0.01680	0.00177	99% (-0.018321, -0.015279)	-29.96	38	$p < 0.001$
Y5%	Chrome	20	0.04835	0.00166	0.00037	-0.02105	0.00170	95% (-0.022136, -0.019964)	-39.24	38	$p < 0.001$
	HCR	20	0.0694	0.00173	0.00039	-0.02105	0.00170	99% (-0.022505, -0.019595)	-39.24	38	$p < 0.001$
Y10%	Chrome	20	0.09325	0.00329	0.00074	-0.02475	0.00264	95% (-0.026437, -0.023063)	-29.71	38	$p < 0.001$
	HCR	20	0.118	0.00175	0.00039	-0.02475	0.00264	99% (-0.027009, -0.022491)	-29.71	38	$p < 0.001$
Y20%	Chrome	20	0.1592	0.00471	0.0011	-0.02800	0.00434	95% (-0.03078, -0.02522)	-20.42	38	$p < 0.001$
	HCR	20	0.1872	0.00393	0.00088	-0.02800	0.00434	99% (-0.03172, -0.02428)	-20.42	38	$p < 0.001$
Y30%	Chrome	20	0.2301	0.00529	0.0012	-0.04895	0.00479	95% (-0.05202, -0.04588)	-32.30	38	$p < 0.001$
	HCR	20	0.27905	0.00424	0.00095	-0.04895	0.00479	99% (-0.05306, -0.04484)	-32.30	38	$p < 0.001$
Y50%	Chrome	20	0.4411	0.0146	0.0033	-0.07950	0.01173	95% (-0.08701, -0.07199)	-21.42	38	$p < 0.001$
	HCR	20	0.5206	0.00783	0.0018	-0.07950	0.01173	99% (-0.08956, -0.06944)	-21.42	38	$p < 0.001$
Y75%	Chrome	20	0.8158	0.0246	0.0055	-0.09535	0.01846	95% (-0.10717, -0.08353)	-16.33	38	$p < 0.001$
	HCR	20	0.9111	0.00876	0.002	-0.09535	0.01846	99% (-0.11118, -0.07952)	-16.33	38	$p < 0.001$
Y100%	Chrome	20	1.2165	0.0178	0.004	-0.07895	0.01363	95% (-0.08767, -0.07023)	-18.32	38	$p < 0.001$
	HCR	20	1.29545	0.00728	0.0016	-0.07895	0.01363	99% (-0.09064, -0.06726)	-18.32	38	$p < 0.001$

Table 4: *Statistical Analysis of Cyan Relative Densities for Tone Wedge Data from Press Prints*

Visual Assessment of ISO Images. The ISO 12640-1 “Wine and Tableware” (N4) and ISO 12640-1 “Bicycle” (N5) SCID images printed using Chrome and HCR Type 1 cylinders on production presses were visually evaluated for legibility, smoothness, sharpness, image detail, and print defects to award ratings. The ratings awarded to Press prints are summarized in Table 5.

ISO SCID Image	Cylinder Type	Production Press					Overall Rating
		Legibility	Tone Smoothness	Edge Sharpness	Image Detail	Print Defects	
“Bicycle” (N5)	Chrome	Excellent	Good	Good	Missing Fine Line	Noticeable Missing Dots	Good
	HCR Type 1	Excellent	Good	Excellent	Excellent	Few Missing Dots	Excellent
“Wine and Tableware” (N4)	Chrome	Excellent	Good	Good	Excellent	Noticeable Missing Dots	Good
	HCR Type 1	Excellent	Good	Excellent	Excellent	Few Missing Dots	Excellent

Table 5. *Visual Analysis of Natural Images Printed on Production Press*

In Press prints, HCR Type 1 cylinders continued to demonstrate superior ability to print the ISO Bicycle fine lines. In addition, the number of missing dots in highlight areas was noticeably reduced when using HCR Type 1 cylinders compared to Chrome. Finally, the use of HCR Type 1 (vs Chrome) cylinders enhanced edge sharpness. Images printed with HCR Type 1 cylinders had darker, sharper edges due to the superior ability of these cylinders to print fine black dots. Based on these findings, Chrome Press prints were awarded an overall rating of Good while the HCR Type 1 Press prints were awarded a rating of Excellent.

Summary and Conclusions

In terms of density, HCR solids exhibit superior density compared to Chrome solids. The density values obtained for Chrome samples were typical of conventional gravure printing; the densities achieved in HCR samples were exceptional and impressive. Visual analysis revealed that HCR’s higher black densities resulted in increased sharpness in the highlight and shadow areas. These results strongly support the conclusion that HCR densities outperform Chrome densities for samples printed using the same screens, engraving methods, ink formulations, and press conditions.

Based on the results just discussed, HCR can achieve higher relative density values compared to Chrome for identically engraved cylinders printed using identical print conditions. This means fully formulated ink could be mixed with extender to match Chrome solid ink densities when printing with HCR cylinders. Extender is significantly less expensive than fully formulated ink, so adding extender simultaneously lowers ink cost. The resulting cost reduction would further improve the overall competitiveness of gravure printing compare to flexographic printing. Governments, especially in Europe, have been tightening regulatory requirements associated with the use of chrome. This trend is expected to continue and could result in a ban on using chrome to plate gravure cylinders. Because HCR coating is an environmentally friendly process which is not regulated, it provides a viable option for engravers, trade houses, and printers to replace Chrome. The results of this research demonstrate that in terms of image quality, HCR is a better option than Chrome and this could potentially accelerate the adoption of HCR.

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