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〈Research Paper〉

Inkjet Printing on the Grain Leather: Evaluation of Line Image Quality on the Grain Leather

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Abstract— This paper addresses factors of line image quality on grain leather printed via inkjet printer. Lines were printed onto coated leather media, and line width, edge blurriness, and edge raggedness were evaluated for line image quality. Various factors influenced to wetting and capillary wicking were studied and found out that wicking through capillary between fibers causes significant feathering on leather surface similar with pulp capillary in copy paper. Polyurethane and acrylic resin coating resulted good image quality by reducing capillary wicking. The mixture of polyurethane and acrylic resin applied on grain leather satisfied with both image quality and surface hand. AllWrite^{TM} ink brought best results of image quality, comparing with VeraPrint^{TM} ink and JetWrite^{TM} ink.

Keywords: *grain, leather, inkjet printing, image quality, finishing*

1. Introduction

Leather is used for many areas, especially in the footwear industry, and the leather manufacturing is one of the oldest ancient technologies along with textiles. There are a number of processes that can produce leather from the skin of an animal. Three major categories of leather in the market are full-grain, collected-grain, and split leather. The full-grain leather is clean natural hides with removed hair, and no sand finishing processes are included to remove imperfections in the process. The full-grain leather allows the best fiber strength and natural breathability resulting in good durability and great comfort, respectively. Corrected-grain leather or top-grain leather has one smooth side and one fuzzy side. The leather hides have both the natural grain sanded off and an artificial grain applied. Split or Suede is leather that the grain was completely removed. Manufacturers usually make suede appear to be full-grain with various technologies.

The processes for producing full-grain leather are divided into two major steps; wet and dry processes. Chemicals are applied in a drum during wet process. After the wet process, finish is applied to achieve desired color and touch during dry process; however, it only can produce limited colors and limited surface designs so it is difficult to satisfy customers' demand. Therefore, development of a new technology and process is required to eliminate the limitations associated with the conventional process. To overcome those limitations, we used an inkjet printing technology to leather product which is widely used in textiles recently along with screen, off-set, and heat-transfer printing. In this study, line image quality on grain leather printed via inkjet printer was evaluated in terms of line width, edge blurriness, and edge raggedness [1-10].

This study will address the understanding of inkjet print quality on grain hide leather. The effects of finishing using various types of polymers

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with different concentration and various inks on line image quality will be discussed, as well as fastness of line.

2. Experimental

Natural grain hide leather was chosen because the grain has good surface whiteness and sharpness with any color inks. Since natural grain has high wicking and absorption properties with color inks, various finishing materials were applied on the leather surface. As described in Table 1, four finishing materials and various compositions were obtained. The finishing materials were applied with knife coating method with 20% pickup ratio, and were dried at the ambient condition. The molecular weight of the polymers in 20% concentration solution was around 2000. The viscosities of tested finishing materials were approximately 750 ps at 20℃. The different finish materials were selected to study effects of types of polymer film, different compositions, and various formulations on line image quality.

A VisionJet system with an Utrajet II inkjet head (Trident International) was used to print a line on the leather. Printing tests were conducting using VersaPrint™ black ink, AllWrite™ black ink, and JetWrite™ black ink by Trident International[5], and the compositions and properties of these inks can be found in Table 2.

A Brookfield viscometer (model DV-1) and a ring tensiometer were used to measure the viscosity and surface tensions of the inks, respectively.

To quantitatively analyze the printed leather, a HP Scanjet 8250 scanner were used to measure reflectance from line images. HP Scanjet 8250 scanner's gamma correction, called 'midtone', was adjusted to get linear relationship between reflectance and 8-bit grayscale. Standard reflectance tiles from Ceram Technology were used to get the value of midtone of the scanner that produced a linear relationship between reflectance and grayscale as shown in Fig. 1.

Analytic tool based on standard (ISO/IEC DIS 13660) was developed to analyze the scanned

Table 1. Description of finish material

Style #		Type	Formulation
Grain Leather	PU-1	Polyurethane	Polyurethane resin
	AC-1	Acrylic Emulsion	Acrylic acid(AA)/ Methylmethacrylate (MMA)/ Butyl methacrylate (BMA)/ 2-ethylhexyloxyacetic acid(EHAA) copolymer
	PU_AC-1	Acryl blend Polyirethane	Isphorone diisocyanate + (ethylene glycol +adipic acid) + Acrylic acid resin (20%)
	PU-2	Polyester Type Polyurethane	4,4-diphenyl methylene diisocyanate + polyester type polyol (adipic acid + 1,4 butane diol)
	PU-3	Isophorone Type Polyurethane	Isphorone diisocyanate + (ethylene glycol +adipic acid)
	PU-4	Polycarbonate Type Polyurethane	4,4-diphenyl methylene diisocyanate + (ethylene dicarbonate + polycarbonate diol and polytetra methylene glycol)
	PU_AC-2	Acryl blend Polyurethane	Isphorone diisocyanate + (ethylene glycol +adipic acid) + Acrylicacid resin (10%)
	PU-5	Polyester Type Polyurethane	4,4-diphenyl methylene diisocyanate + polyester type polyol (adipic acid + 1,4 butane diol) and polytetramethylene glycol (1:3)
	PE	Polyethylene Resin	Polyethylene (ethylene +acrylic acid)
	AC-2	Acryl Emulsion	Acrylic acid(AA)/ Methylmethacrylate (MMA)/ Butyl methacrylate (BMA) copolymer
	RPE100	EVA Resin	Poly(ethylene-co-vinyl acetate) (VA 15%)
	PU-6	Polyester Type Polyurethane	4,4-diphenyl methylene diisocyanate + polyester type polyol (adipic acid + 1,4 butane diol)

Table 2. Ink properties

Ink type	Description[a]	Surface tension[b] (mN/m)	Viscosity[c] (cP)
VersaPrint	Polyalkylene glycol: 60 – 80% Polyalkylene glycol alkyl ether: 15 – 40% Colorant: Solvent black 29	24	70
Jetwrite	Fatty ester: 50 – 60% Fatty acid: 30 –40% Azine compound, and Aniline: 5 – 15%	30	39
Allwrite	Alkylene glycol alkyl ether: 65 – 75% N-propyl alcohol: 10 – 20% Acrylic resin: less than 5% Colorant: Solvent black 48	31	14

a. Information provided by Trident International.
b. Data measured by a VCA2500KE Contact Angle Surface Analysis System.
c. Data measured by a Brookfield Viscometer.

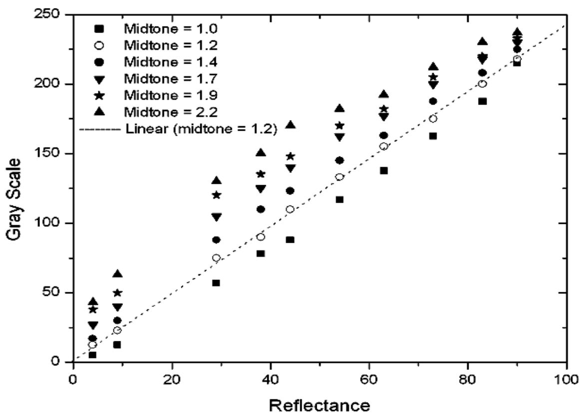


Fig. 1. Relationship between grayscale and reflectance with different midtone values.

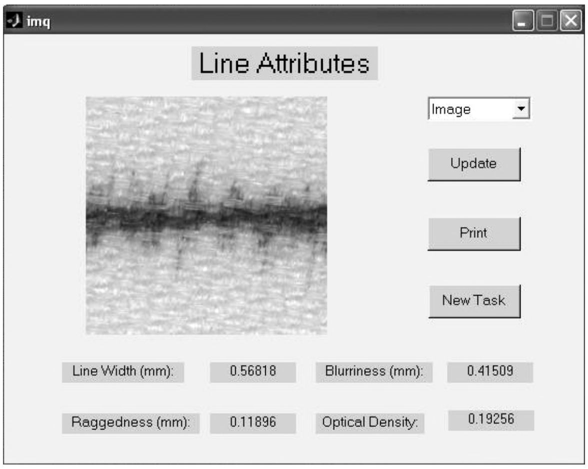
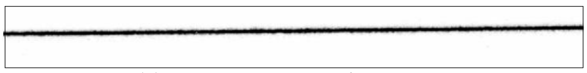


Fig. 2. Line width, Blurriness, and Raggedness results after running MATLAB Image quality program based on standard (ISO/IEC DIS 13660).

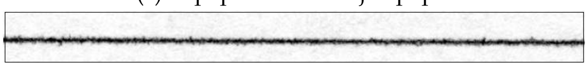
images using a MATLAB program, as shown in Fig. 2. The output of the tool was print quality in terms of line width, edge blurriness, and edge raggedness. Line width is width of the line measured normal to the line between both edge thresholds. Edge blurriness is the haziness or indistinctness of outline. Edge raggedness is the geometric distortion of a straight-lined edge from its ideal position. The value of raggedness is the standard deviation of the residuals calculated perpendicular to the fitted line.

3. Results and Discussion

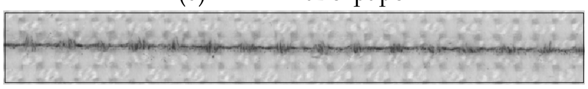
A study is conducted to investigate the effects of various finishing materials of grain leather on the image quality. Fig. 3 shows line images printed on copy paper, inkjet premium paper,



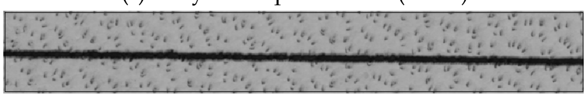
(a) Hp premium inkjet paper



(b) Plane paper



(c) Polyester spun fabric (Plane)



(d) Unfinished grain leather

Fig. 3. Images of wicking on unfinished grain leather with VersaPrint ink. Wicking on (a) HP silica coated inkjet premium paper, (b) Office depot plane copy paper, (c) polyester spun plane fabric, and (d) unfinished grain hide leather.

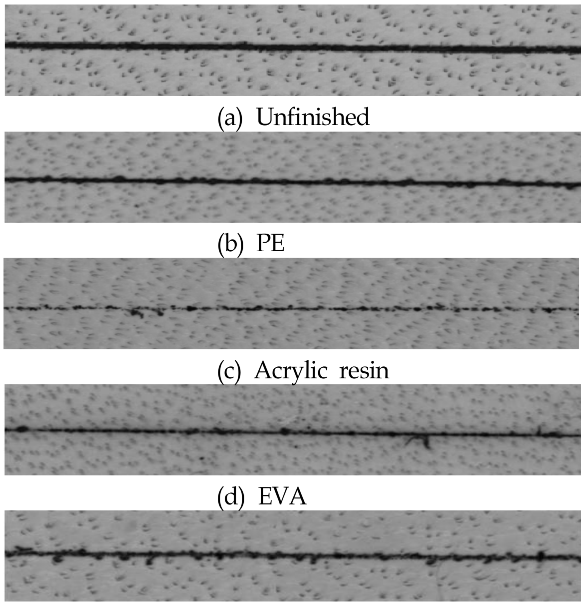
polyester spun woven fabric, and unfinished grain leather, and illustrates that the main reason of poor image quality on leather media is capillaries on surface. Printed inks are mostly spread in the perpendicular direction to the printed line (ink spreads through capillary beneath surface of the leather). Fig. 3 (a) shows that ink was printed on surface coated with silica pigment particle where inks almost penetrate directly. When the ink impacts on coated surface, the ink wicked between particles.

In Fig. 3 (b), we can see the feathering, where wicking process is caused by capillary in the pulp fibers. Fig. 3 (c) shows the wicking through the filling yarn of the polyester fabric, which is very important on image quality and varied by geometric structure of the polyester fabrics. In Fig. 3 (d), ink absorption on grain leather is very similar to liquid absorption on commercial copy paper. Since the structure of protein fiber in the leather is similar to the pulp structure in the copy paper, these similarity may build similar wicking channel of capillary; however, hide grain leather has marks from skin pores and are not smooth like paper. To reduce such a fast feathering, the original leather was applied with various polymer films similar with coated paper.

Since the main reasons of wicking is capillary force and most effective way to reduce the wicking processes is coating, image quality based these coating materials and formula will be presented first, and then the effects of ink will follow.

3.1 Effect of Polymer on Line Image Quality

In the previous study[10], the impacted ink drop wicks along pore capillary between fibers which make random ragged pattern at edge of printed line. Fibrous inter-structure beneath leather surface is structurally associated with pulp fiber structure of plane copy paper. Thus, line image quality is expected to be not better than any other coated substrates. Results of image quality on four totally different coating materials (polyethyleyne, acrylic resin, poly(ethylene-co-vinyl acetate), and polyurethane) were compared in Table III and Fig. 4.



(a) Unfinished (b) PE (c) Acrylic resin (d) EVA (e) PU

Fig. 4. Effect of coating materials on image quality for (a) unfinished (b) Polyethylene (PE), (c) Acrylic resin (AC-2), (d) Poly(ethylene-co-vinyl acetate) (RPE100), and (e) Polyurethane (PU-6).

Table 3. Various image quality results with different coating material

Product name	Materials	Line width (mm)	Blurriness (mm)	Raggedness (mm)
Original	None	0.28	0.072	0.33
PE	Polyethylene	0.12	0.12	1.0
AC-2	Acrylic Emulsion	0.16	0.19	0.21
RPE100	Poly(ethylene-co-vinyl acetate)	0.22	0.10	0.19
PU-6	Polyurethane Emulsion	0.22	0.082	0.12

Fig. 4 visually shows lines that printed on different coating materials with VersaPrint™ ink. Fig. 4 (a) shows that an ink was printed on unfinished grain hide while (b)-(e) show that the ink was printed on resin finished hide. In Fig. 4 (a), wide line width and irregular peaks were observed, and in Fig. 4 (b)-(e), relatively consist lines were observed. In Table III, line image qualities of PE coated hide have good line width, moderate blurriness, and poor raggedness, while acrylic resin, EVA, and polyurethane coated samples show good line width and raggedness with moderate blurriness. The only data obtained from acrylic resin and polyurethane coated samples were used in this study because of material limitation of EVA.

3.2 Effect of Types of Acrylic and Poly urethane Resins on Line Image Quality

Line image qualities of various coated leathers are different with capillary volume, structure, and size, which can be changed by pore size, coating method, and components of coating materials. Finishing is usually required to improve the image quality of lines printed on most of leathers. As shown in earlier works [7-10], acrylic finishing on polyester fabric are significantly affect to image quality, while polyurethane finishing did not affect much on printed fabric. The results shown in Table IV reveal that line image quality of fabric finished with acrylic and polyurethane resin is better than those of unfinished. Acrylic resin and polyurethane resin are common materials for various applications of the leather. The effects of both finish materials are important to achieve good line image quality of leather printing.

These finish materials well cover capillary spaces on leather surface, which can block liquid flow through pores by liquid capillary forces. Table IV shows test results of line image qualities including line width, edge blurriness,

Table 4. Various image quality results with different formulation of acrylic resin

Product name	Resin type	Materials	Line width (mm)	Blurriness (mm)	Raggedness (mm)
Unfinished		None	0.28	0.072	0.33
AC-1	Acrylic	AA+MMA+BMA+EHAA copolymer	0.12	0.072	0.080
AC-2		AA+MMA+BMA copolymer	0.16	0.19	0.21
PU-2	Polyuret-hane	4,4-diphenyl methylene diisocyanate + polyester type polyol (adipic acid + 1,4 butane diol)	0.21	0.11	0.15
PU-3		Isphorone diisocyanate + (ethylene glycol +adipic acid)	0.18	0.13	0.13
PU-4		4,4-diphenyl methylene diisocyanate + (ethylene dicarbonate + polycarbonate diol and polytetra methylene glycol)	0.19	0.083	0.18
PU-5		4,4-diphenyl methylene diisocyanate + polyester type polyol (adipic acid + 1,4 butane diol) and polytetramethylene glycol (1:3)	0.21	0.083	0.56
PU-6		4,4-diphenyl methylene diisocyanate + polyester type polyol (adipic acid + 1,4 butane diol)	0.22	0.082	0.12

and edge raggedness for acryl and polyurethane finished grain leathers printed with Versa ink. For Acrylic resin finish, AA+MMA+BMA+EHAA copolymer (AC-1) and AA+MMA+BMA copolymer (AC-2) are used. Both materials are well functioning to cover capillary pores on leather surface to get good line image qualities. The ranges of line width, blurriness, and raggedness for polyurethane finished leathers are 0.12 to 0.16 mm, 0.072 to 0.19 mm, and 0.080 to 0.21, respectively. The best image qualities were achieved with AC-1 acrylic resin finish. Usually acrylic resin shows uniform coating on the leather surfaces which induced good image qualities; however, feeling and stiffness after finishing treatment were not good grades, so original touches or hand were compensated. Thus, various leathers finished with polyurethane resins were tested. The ranges of line width, blurriness, and raggedness for polyurethane finished leathers are 0.18 to 0.22 mm, 0.082 to 0.13 mm, and 0.12 to 0.56, respectively. Even though the polyurethane finish has relatively good hand, still the image qualities were not associated with those for acrylic finished grain leathers.

3.3 Effect of Acryl Resin Contents of Poly urethane Mixture on Line Image Quality

Image qualities of acrylic resin finished leathers were very good comparing with other coating materials including polyethylene, EVA, and even polyurethane resin; however, the touch or hand of acrylic resin finished leathers need to be improved. In this section, mixture of these resins on image qualities is discussed. Two mixtures with different acrylic resin contents are compared in Table V. PU_AC-2 consists of polyurethane with isphorone diisocyanate with ethylene glycol and adipic acid and 10% of acrylic acid resin while PU_AC-1 is made of PU_AC-2 with 10% of acrylic resin. Both resin finished leather obtained relatively good hand, and image qualities of PU_AC-2 and PU_AC-1are similar except edge raggedness which are 0.33 for PU_AC-2 and 0.15 mm for PU_AC-1.

3.4 Effect of Different Inks on Line Image Quality

Line image qualities of printed leather are influenced by ink viscosity, interaction between ink and substrate, wicking, penetration, and especially drying rate at the surface. Good drying, wicking, and penetration are required to improve the image quality of lines printed on leather. In earlier works[7-10], Allwrite™ ink printed on unfinished/finished textile fabric significantly increased line width and other qualities, while VeraPrint™ ink and JetWrite™ ink did not show impressive line quality improvement on the fabrics. The results of image quality with different inks, shown in Table VI, are similar with those for polyester fabrics. The results shown in previous sessions were obtained with VeraPrint™ ink. When VeraPrint™ ink, glycol-based ink, is printed on unfinished/finished hide leather, the ink absorbed into substrate and spread on the surface simultaneously. Oil based JetWrite™ ink was also used to show the importance of wetting/

Table 5. Various image quality results with different formulation of acrylic–polyurethane mixture

Product Name	Ink	Materials	Line Width (mm)	Blurriness (mm)	Raggedness (mm)
Original		None	0.28	0.072	0.33
PU_AC-2	Versa Print	Isphorone diisocyanate + (ethylene glycol + adipic acid) + Acrylic acid resin (10%)	0.19	0.080	0.33
PU_AC-1		Isphorone diisocyanate + (ethylene glycol + adipic acid) + Acrylic acid resin (20%)	0.18	0.075	0.15

Table 6. Various image quality results with different inks

Line width

Style #	Type	Allwrite	Jetwrite	Versa
No Finish		0.27883	0.072338	0.334135
AC-1	Acrylic Emulsion	0.108378	0.135205	0.122055
PU_AC-1	Acryl blend Polyirethane	0.118899	0.12942	0.180975
PU-2	Polyester Type Polyurethane	0.11995	0.239375	0.165195
PE	Polyethylene Resin	0.11942	0.20097	0.117845
RPE100	EVA Resin	0.140995	0.351955	0.22569

Blurriness

Style #	Type	Allwrite	Jetwrite	Versa
No Finish		0.073128	0.066814	0.072338
AC-1	Acrylic Emulsion	0.067077	0.095486	0.071549
PU_AC-1	Acryl blend Polyirethane	0.065236	0.117058	0.075058
PU-2	Polyester Type Polyurethane	0.059449	0.12679	0.086017
PE	Polyethylene Resin	0.05524	0.11811	0.103117
RPE100	EVA Resin	0.064184	0.162825	0.103642

Raggedness

Style #	Type	Allwrite	Jetwrite	Versa
No Finish		0.093485	0.115235	0.334135
AC-1	Acrylic Emulsion	0.061713	0.087896	0.079969
PU_AC-1	Acryl blend Polyirethane	0.28794	0.890155	0.15394
PU-2	Polyester Type Polyurethane	0.097706	0.071044	0.059022
PE	Polyethylene Resin	0.203425	0.15568	0.99891
RPE100	EVA Resin	0.17608	0.71201	0.186215

soaking properties on image quality. The properties of oil based ink are similar to those of glycol based ink, which includes this interaction between ink and substrates. Since Allwrite™ ink evaporated before significant feathering or bleeding, this alcohol based ink brought best results of all on the grain leathers.

4. Conclusions

The effect of factors on image quality of lines printed with inkjet printer were discussed. Wicking through capillary between fibers cause significant feathering on leather surface, which structure is similar to pulp capillary in copy paper. Polyurethane and acrylic resin are very food candidates for coating materials to reduce capillary wicking. Acrylic resin coating on leather induced best performance of image quality of line printed on finished leathers; however, acrylic resin coated grain leather is stiff and bad hand. The mixture of polyurethane and acrylic resin applied on grain leather makes satisfaction of image quality and leather hand. Three different types of inks were applied to enhance image quality. Because of fast evaporation rate of AllWrite™ ink, the ink brought best results of image quality of all.

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