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UV Ink-Jet printability and durability of stone and foil

ABSTRACT

The use of ultraviolet (UV) printing technology has impacted printing industry in last years due to its applicability on many different »absorptive« as well as »non-absorptive« printing materials. The printability of building materials and recycled foils is relatively unknown. For primary building materials like stones, functionality can be explored with the use of UV printing technology; increased visual, informative effect or even "creative printing" of buildings. Also several aspects of recycled foils reusability as a printing material could be find (printed packaging material or also like secondary building materials). In the present study, printability of the stone and recycled foil and durability of UV prints was explored by means of macroscopically and microscopically characterization. Results indicate that higher print quality can be achieved on polished stone and on coated foil, which surfaces have higher smoothness. Durability of UV prints at freezing is higher at unpolished stone and coated foil that is at materials with the higher surface energy.

KEY WORDS
UV inkjet, printability, durability, stone, recycled foil, image analysis

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Introduction

Printing technology has developed rapidly in past decades and has been expanded to all areas of our lives. A special attention has been drawn to UV printing technology, primary introduced in 1970's, yet fully developed in late 1990ies (Webster, 1998; Pira international, 2009; Neral et al., 2006; Mirschel et al., 2014). UV inks are unique in the way of drying (Hoff, 1997; Muck et al., 2009). Opposite to traditional water based inks, UV inks stay unabsorbed on the surface of material and are instantly dried into hard film when exposed to UV rays emitted by UV reflectors included in printing system. One of the main advantages of the new UV printing technologies is that it can be introduced to whole range of new printing, rigid and non-absorptive surfaces such as foils, ceramics, stones, which are not printable by traditional water based ink technologies. Also, UV inks are rapid in curing, they have excellent color value and saturation and they are highly durable which permits their usage for example in outdoors conditions (Eldred, 2001; Adam and Dolin, 2002).

Disadvantages are that they can have poor abrasion/adhesive resistance and can be less flexible than other ink systems. The UV-curable inks and varnishes typically consist of monomers, oligomers, pigments and photoinitiators. The photoinitiators are the catalysts that react to UV light of a certain wavelength, triggering polymerization, which form a continuous solid or dry film (Neral et al., 2006;, Gregor-Svetec et al., 2008). On the polymeric substrate printed by UV IJ technology some articles present printability of materials including polyethylene (PE), polypropylene (PP), and polyester (PES) (Agfa, 2009; Printing Impressions, 2009). To assess the potential of substrate for printing two parameters are important: a runability and a printability. The runability is defined as possibility of printing material to traverse through the printing machine while the printability (the print quality) is set by the range of different parameters such as dot formation, dot gain, mottling, colour gamut and is used to evaluate the final quality of prints (Printing Impressions, 2009; Kipphan, 2001). Stone material has due to its stiffness and weight limited runability. For this reason, only two printing technologies could be applied on the stone surfaces; one is a screen-printing and another is an ink-jet printing. In present study, the printability of recycled foil and stone with the UV inkjet printing technology and the durability of UV prints were explored.

Materials and methodes

As a building material white dolomitic marble (from Greece) known as Volakas marble was used. Two different stone substrates were chosen for study: polished and honed surfaces. The thin plastic foil was produced from the 100% recycled low-density polyethylene LDPE chips, made from the separately collected waste packaging in Slovenia. A part of the foil was precoated in order to increase the saturation of color prints. A matt white coating based on PVC was applied with the screen-printing. So four different printing surfaces were analyzed; polished stone and unpolished stone, uncoated recycled foil and white coated recycled foil.

The printability of stone and recycled foil was eval uated using an optical microscopic technique and image analysis. Before printing, total surface energy measured on the base of Van Oss method (Van Oss, 2002) were carried on printing materials. Surface roughness/smoothness was determined with an air leak method using Bendtsen method.

The surface of unprinted materials was captured with the optical microscope Leica EZ 4D and CCD camera in order to determine mottling. Mottling defines the surface non-uniformity of printing material. It was determined using macro developed by Maja Stanić in ImageJ platform. The amount of non-uniformity is calculated on the basis of the histogram of the image. It measures the difference between the upper Ux and lower Lx values of the image histogram. Ux is calculated as the mean of the intensities between median and maximum values of the histogram. Lx is calculated as the mean of the intensities between minimum and median values of the histogram. The amount of the non-uniformity is expressed as the non-uniformity index: NU = Ux – Lx. The greater the NU value, the higher amount of mottle is present.

The stone and recycled foil were printed with the UV ink-jet printer Océ Arizona. The following printing conditions were applied: 8 printing heads Toshiba T Tec (2xCMYK), high quality printing rate (12 m^2/h), piezoelectric technology (VariaDotTM (6 to 42 pL)) and use of UV reflectors (2.3 mW/cm^3, 800 ^{O}C).

The printed surfaces were captured with the optical microscope Leica EZ 4D and CCD camera at two magnifications: 8-x and 35-x. Parameters of capturing were: format size: 1600 x 1200 ppi, brightness: 90 %, gamma: 0.80, saturation: 143.00. Use of two different magnifications enabled to evaluate raster tone value (ink coverage on printed surface – A %) and dot formation of single raster printed dot (area, perimeter, circularity). Parameters were determined in Java platform with freely available image analysis software ImageJ (ImageJ, 2008), with new developed and upgraded macros. All measurements were repeated ten times and standard deviation was determined for each separate measurement.

The printed stone and recycled foil were exposed to 12 cycles of freezing in air and thawing in tap water according to standardized method for determination of frost resistance of natural stone (EN 12371) (Slovenian institute for standardization, 2008). The durability of UV ink prints on polished and unpolished stone and on uncoated and coated foil was evaluated by measuring the raster tone value (ink coverage on printed surface – A %) and dot formation. On the printed recycled foil the adhesiveness of UV ink was evaluated also by cross cutting method – Byko-cut universal.

Results

The characterization of unprinted surfaces

The results of surface energy, surface non-uniformity and roughness/smoothness measurements are given in the Table 1.

Table 1
Total surface energy, Non-uniformity of substrate surface (NU) and roughness (RB) of printing materials.

Sample	γ_S^{TOT} (mJ/m²)	NU (-)	RB (ml/min)
Unpolished stone	41.22	7.95 ± 0.52	1600 ± 335
Polished stone	36.60	5.85 ± 0.32	402 ± 210
Uncoated recycled foil	36.56	10.55 ± 0.82	123 ± 109
Coated recycled foil	38.23	9.39 ± 0.52	53 ± 25

The results in Table 1 show that polishing of stone and coating of foils has very good effect on surface uniformity. Non-uniformity, NU of surface and roughness are higher for uncoated recycled foil and honed stone.

NU is lower on polished stone surface. The correlation between surface uniformity and surface roughness is very good. The same effect has white precoating on foils. Uncoated recycled foil has a lot of inclusions of particles of different size (from few µm to several hundred µm), which make the surface of foil more rough and uneven in comparison to coated foil, where these particles are mostly covered. The value of surface energy is higher on unpolished stone and on coated recycled foil surface. The higher surface energy of coated foil is the consequence of applied coating material, as PVC has higher surface energy as PE.

The characterization of printed surfaces before and after ageing

The captured images of UV print by optical microscope at 8x magnification on the uncoated and coated recycled foil and on the polished and honed surface of stone

Table 2
Captured images of UV prints on stone and recycled foil before and after ageing.

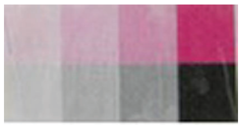
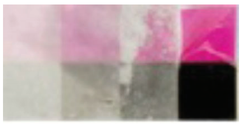
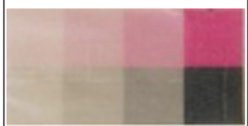
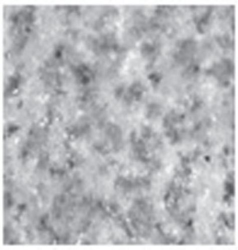
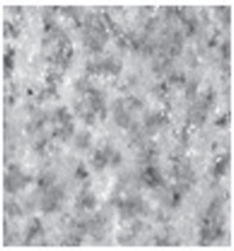
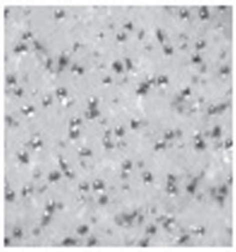
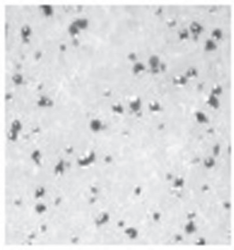
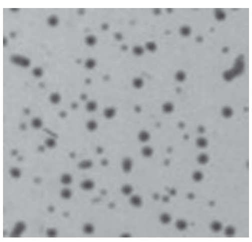
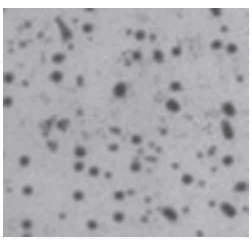
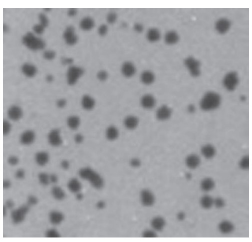
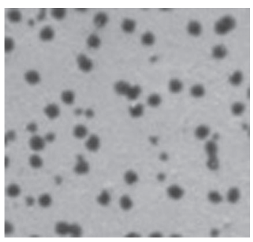
Sample	Unpolished stone	Polished stone	Uncoated recycled foil	Coated recycled foil
Before freezing				
After freezing				

Table 3
Formation of printed dots before and after ageing. The images were captured on 20% raster tone value of black printed patches on recycled stone and foil.

Unpolished stone before freezing	Unpolished stone after freezing	Polished stone before freezing	Polished stone after freezing
			
Uncoated recycled foil before freezing	**Uncoated recycled foil after freezing**	**Coated recycled foil before freezing**	**Coated recycled foil after freezing**
			

before and after freezing are given in the Table 2. In the Table 3 the captured images at 35x magnification on 20% raster tone value patches of black colour are seen.

From the analyses of captured images (Table 3) we can see that the raster tone value and dot formation have stayed relatively unchanged after freezing and thawing of both types of unpolished stone and recycled foil, whereas the visual and quantitative comparison of two images (before and after freezing) of polished stone gives clear indication of decreased raster tone value.

The raster tone value (A%) and dot formation (area, perimeter and circularity) were determined with the software ImageJ. Images captured by the optical microscope were exported in tiff format and transformed in 8-bit images. Circularity of dots was determined as 4*pi (Dot Area / Perimeter^2). All parameters were measured on 20% raster tone value patches of the black colour (images in the Table 3). The results of measured parameters before freezing are given in the Table 4 and after freezing in the Table 5.

Table 4

Raster tone value (A%) and dot formation of printed stone and foil before ageing (parameters were determined on 20% raster tone value of black colour).

Sample	A (%)	Dot Area (pixl.2)	Perimeter (pixl.)	Circularity (-)
Unpolished stone	34.50 ± 1.81	470.68 ± 260.03	103.18 ± 31.69	0.59 ± 0.12
Polished stone	26.20 ± 1.42	358.31 ± 200.21	68.21 ± 18.50	0.87 ± 0.08
Uncoated recycled foil	13.83 ± 2.01	352.92 ± 188.27	72.11 ± 21.13	0.82 ± 0.09
Coated recycled foil	15.42 ± 1.27	436.10 ± 82.99	78.01 ± 7.28	0.90 ± 0.04

Table 5

Raster tone value (A%) and dot formation of stone and printed foil after ageing (parameters were determined on 20% raster tone value of black colour).

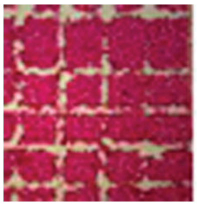
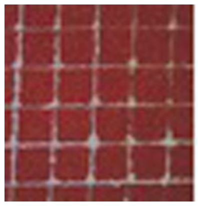
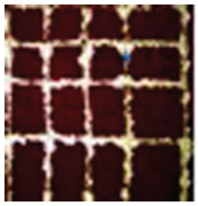
Sample	A (%)	Dot Area (pixl.2)	Perimeter (pixl.)	Circularity (-)
Unpolished stone	32.8 ± 1.80	468.00 ± 258.10	103.10 ± 30.91	0.61 ± 0.11
Polished stone	15,4 ± 1.38	352.38 ± 198.19	65.21 ± 17.50	0.88 ± 0.10
Uncoated recycled foil	13.65 ± 1.98	355.92 ± 183.21	71.19 ± 20.10	0.81 ± 0.15
Coated recycled foil	15.32 ± 1.25	434.10 ± 81.87	79.01 ± 7.18	0.90 ± 0.03

Stone polishing has a very good effect on the dot formation (Table 4). The printed dots are smaller, but theirs circularity is much higher. Precoating has also a good effect on the dot formation. Cicularity is more uniform and a little bit higher than on the uncoated surface of foil (Table 4).

After 12 cycles of freezing in air and thawing in water the dots area and dot formation remained relatively unchanged at both foils (uncoated and coated) and also for honed marble, unpolished stone surface (Table 4, 5). In the case of polished stone individual detachments of ink and decrease of color value can clearly be identified even with naked eye. The visual observation is also confirmed with the microscopically qualitative and qualitative analysis. As the dot area and dot formation on the uncoated and coated foil stayed unchanged after ageing, the additional method for evaluating the adhesiveness of ink on the foil surface was applied- cross cutting method by Byko-cut universal tester. The results are given in the Table 6.

Table 6

Results of analyzing prints (ink) adhesiveness by cross cut test- Byko-cut tester. 100% raster tone value of magenta patches was analyzed.

Sample	Uncoated recycled foil	Coated recycled foil
Before freezing		
After freezing		

From the Table 6 we can clearly see, that coating has good impact on the ink adhesiveness. The stability of prints on the coated recycled foil before and after freezing is much better compared to prints on the uncoated recycled foils.

Discussion

The printability of stone is relatively good on both, unpolished and polished samples. The similar conclusion can be given for printability of recycled foil both, uncoated and coated samples. The results in the Table 1 show that polishing and coating have very good effect on the surface uniformity (lower light scattering), since NU is lower on the polished stone and on the coated recycled foil. The correlation between surface uniformity and surface roughness is also very good. The polished stone surface and coated recycled foil have impact on the print quality. Polishing and coating influence the raster tone value of UV prints on different way.

Stone polishing has a very good effect on the dot formation. The printed dots are smaller, but theirs circularity is higher. Best dot formation means also best final print quality (Table 4). For good printability circularity of dot has to be near 1 if the ideal circular raster element is used. Similar conclusion can be given for the influence of precoating on foil. It has a good effect on the dot formation; the uniformity of the printed dots and circularity are higher.

Visual appearance at all samples (stone and foil) before and after frost resistance ageing shows that quality of UV prints has decreased after 12 cycles of freezing and thawing only at polished stone. Parts of printed ink have detached from the surface while dot formation has stayed relatively unchanged and the raster tone value (ink coverage on printed surface – A%) has almost twice lower value. In detached area no remaining of ink was observed (Table 2), which means that once the print is removed the original stone surface is resumed.

Higher surface energy of the unpolished stone and coated recycled foil surface can be connected with the better adhesiveness of UV inks before and especially after freezing. Lower surface energy of polished surface could explain poor adhesion of UV ink dots on polished surface of stone exposed to artificial ageing. Poor adhesion of UV ink on the polished stone also means that printed ink can be easily removed, which can be beneficial if short-term print is desirable.

Conclusion

The print quality and durability of prints on marble surfaces and recycled foil highly depends upon smoothness/roughness of the surface. Polishing of the stone surface reduces raster tone value and increases dot circularity. White coating on foil increases raster tone value and also dot circularity. Higher print quality with more uniform and circular raster dots is obtained at polished marble and coated recycled foil. The increase of raster tone value – dot gain can be controlled in prepress, while dot circularity (formation) depends only upon ink and surface substrate interaction.

Present results show that UV printing technology can be successfully applied on building materials such as polished and honed marble and also on recycled polymer foils. White precoating on foil leads to increase of surface energy and has good effect on printability of foil and also durability of printed foil.

On the other hand, just short exposure to cycling freezing and thawing indicates that higher printability is connected with lower durability of prints in the case of polished stone. This can be turn to advantage of short term prints on stone surface where once out of date information can be easy removed and exchanged.

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References

1. Adam, M. J., Dolin, P. A. (2002) Printing Technology. Albany, NY, Delmar, pp. 411.
2. Agfa. (2009), UV Cureble Inks.[Online] Available from: www.agfa.com/en/gs/binaries/wp_uvcurableinks_20070601_tcm219-32658.pdf/ [Accessed 26th January 2014].
3. Eldred, R. N. (2001) What the Printer Should Know about Ink. Sewickley, PA, GATFPress.
4. Gregor-Svetec, D., Muck, T., Golob, G. (2008) Surface properties and UV ink-jet printability of recycled polyolefins. In: N. Enlund & M. Lovreček (eds.): Advances in printing and media technology. Vol. 35: Proceedings of the 35th International Research Conference of Iarigai, Valencia, Spain, Darmstadt, Germany; Acta Graphica Publishers, pp. 203-211.
5. Hoff, S. (1997) Screen printing: a contemporary approach. Albany: Delmar Publishers, pp. 177, 178.
6. ImageJ. (2008): Image Processing and Analysis in Java. [Online] Available from: http://rsb.info.nih.gov/ij/index.html/ [Accessed 4th February 2014].
7. Kipphan, H. (2001) Handbook of print media : Technologies and Production Methods. Berlin, Springer.
8. Mirschel, G., Daikos, O., Heymann, K., Scherzer, T., Genest, B., Sommerer, C., Steckert, C. (2014) In-line monitoring of the conversion in UV-cured printed layers by NIR spectroscopy in an offset printing press. Progress in Organic Coatings, vol. 77, Issue 3, 719-724.
9. Muck, T., Javoršek, D., Kreft, M. (2009) Use of confocal microscopy as a nondestructive method in the study of ink jet dot formation. Journal of imaging science and technology, vol. 53, no. 4, 040201/1-040201.
10. Neral, B., Šostar-Turk, S., Vončina, B. (2006) Properties of UV- cured pigment prints on textile fabric. Dyes pigm., vol. 68, 143-150.
11. Pira international. (2009) The future of UV inkjet. [Online] Available from: http://profitthroughinnovation.com/emerging-markets/the-future-of-uv-inkjet.html/ [Accessed 18th December 2009].

12. Printing Impressions. (2009) [Online] Available from: http://www.na.flintgrp.com/news/NewsPrintingImpressions05.pdf/ [Accessed 28th January 2014].
13. Slovenian Institute for standardization (2008) SIST EN 12371. 2008: Natural stone test methods: determination of frost resistance. Slovenia, SIST.
14. Van Oss, C. J. (2002) Use of Combined Lifshitz-van der Waals and Lewis Acid-Base Approaches in Determining the Apolar and polar Contributions to Surface and Interface Tensions and Free Energies, J. Adhesion Sci. Technol, 16 (6), 669-677.
15. Webster, G. (1998) Chemistry & Technology of UV & EB Formulation for Coatings. Inks & Paints, vol. II. London: Sita Technology.