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INFLUENCE OF THE UNCOATED PRINTING SUBSTRATES ON THE QUALITY OF THE MONOCHROMATIC DIGITAL PRINTING

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Abstract: It has been analyzed in this paper how the different types of uncoated papers can influence the quality of the monochromatic screen reproduction. In experiment actual monocromatic digital printing technologies were used: electrophotography, ink jet, digital screen printing, digital offset printing. The analysis comprised determination of dot gain (X-rite DTP 41) and determination of deviations of printed screen elements (Personal IAS). The analysis showed that qualitative monochromatic impression was obtained on Xerox 250. From the tonal point of view, harmonized screen reproduction was achieved on paper adapted for digital printing process. The round screen elements did not print as the smallest ones. The results show that smallest printed screen elements were obtained by Xerox 250 (Δd_{Arc}=45,3 μm, Δd_{Nav}=46,6 μm, Δd_{Arc}=61,8 μm), while greatest printed elements were obtained on Riso (Δd_{Arc}=172,4 μm,Δd_{Nav}=154,4μm, Δd_{Arc}=148,9 μm).

Key words: *uncoated papers, monochromatic digital printing, dot gain, reproduction quality*

1. INTRODUCTION

In regard to the standard papers, it can be supposed that toner would better adhere to the adapted uncoated printing substrate (specific characteristics of the printing process). It means achieving more qualitative reproduction at the same time which is visible in broader achromatic tonal range (from 1 to 99% halftone value). If the adherence of toner is as good on standard paper is analyzed in this paper. Densitometric measurements of reflectance factor (β) are the useful way for observing the bonding quality of a toner onto the printing substrate. If the reflectance factor is known it is possible to calculate the optical inking density (D), surface coverage (F_D) and the dot gain (Z). It is possible to observe easy these three values during the printing process (Kipphan, 2001).

Monochromatic digital printing systems are at the moment irreplaceable in office business as well as in DTP. With their quality and printing velocity they are used more and more for commercial (publication) printing, for printing longer runs. They are technologies which used in their work: the unchangeable "master" printing form (waterless digital offset, digital screen printing), virtual "masterless" printing form (EP=electrophotography) and technology without the printing form (IJ=InkJet) (Kipphan, 1993).

$$D = \log 1/\beta = I_o / I \quad \text{(a)}$$

$$F_D(\%) = \frac{1-10^{D_R}}{1-10^{D_V}} \cdot 100\% \Rightarrow Z(\%) = F_D(\%) - F_F(\%) \quad \text{(b)}$$

β = reflectance factor
I_O = light remitted by blank paper
I = light remitted by ink film
F_D = area coverage in the print
D_V = solid tone density
D_R = halftone density
Z = incrased ton velue
F_F = area coverage on the orginal file

2. THEORETICAL PART

The development of the printing techniques is inconceivable without the new toner formulations which are decisive for achieving higher reproduction quality. By decreasing the dynamic coefficient of viscosity and the sizes of toner particles, the realization of thinner screen elements was enabled. Such trend influences directly the construction of more precise EP systems (ROS and LED writing heads) as well as all smaller nozzles in InkJet printers (Cheng, et al., 2001).

2.1. Uncoated papers

Paper is a flat substance composed of plant fibers which are mechanically or thermally- mechanically treated. For the needs of cheaper monochromatic digital printing not refillerd printing substrates are used, i.e. uncoated paper. Because of its uncoated surface such paper accepts well all the types of inks, some of which are more or less absorbed into the paper surface (Golubović, A.,2003).

The following ones belong to the group of uncoated papers: offset papers, papers for IJ, recycled papers, and papers for EP. The production technology of such papers is characterized by the process without the surface coating. The only differences exist in different quantities of particular fiber raw material (cellulose, ground wood pulp and waste paper) as well as in the quantity of filler and glue.

For higher quality, the papers for the digital printing techniques must be completely adapted to the printing technique. Paper for EP printing must satisfy two basic conditions: it must have grater surface electric resistance (electric conductivity) and small quantity of humidity in its composition (which causes the dissipation of the electric charge before the application of toner). Paper for IJ printing demand strictly controlled capillary absorbance. Too high absorbance will result in depth bleeding (visible on the back side of the impression) while too low absorbance will result in surface spilling (Lemperth., Ingvar, 2001).

Offset paper is uncoated paper dedicated for printing in offset printing technique. It is machine- finished paper which gets its roughness during the production on the machine for paper production. Offset paper is produced passing through the calendar machine. It is not subsequently glazed (it has not passed through the glazing machine which are used in making papers with high smoothness).

Recycled paper is produced from the secondary raw materials. The need for recycled paper is continuously growing and the share of the recycled paper production is about 609% in the total paper production. The basic raw material for the production of such paper is the old waste paper whose share is about 85%. In the production process 14% of fillers and 0,5% of glue is added to such paper. Because of its weak mechanical and optical properties the old paper can be recycled 3 to 5 times. (Walenski, 1994).

2.2 Digital printing techniques

Digital waterless offset printing is the printing form which contains the oleophobic layer on the surface which is selectively removed during the preparation process with the heat aided laser. By positioning the IR (Infra Red) laser heads immediately next to the basic cylinders the multicolour machines were made with the automatic production of "master" printing form. By the application of the offset printing unit (pressures in the contact zone p=3 MPa) and paste ink (η=80 Pa·s) the final print is obtained on the printing substrate. The drying process is complicated and it is the combination of the physical drying (evaporation and absorption of ink into the printing substrate) and the chemical drying (oxypolymerization process in the surface layer of a print).

Digital screen printing technique is characterized by the printing form made from the stencil material which is stretched on the plate cylinder. Above the plate cylinder the thermal head is positioned which performs negative imaging. During the imaging the fibrous material is burned through and the tiny holes are formed, i.e. the future "master" printing elements. Inks for such printing process must be liquid ones, whose basis is the watery-oily emulsion with the black pigment particles less than 1 μm. For achieving the visible print, the ink has to be squeezed with the roller through the holes, after which it ends on the printing substrate.

For the print quality, except the satisfying penetration ability of ink, the absorption ability of the printing substrate is also important. Only the uncoated papers (greater surface roughness) give instantly dry print (Kipphan, 2001).

EP is the printing process based on the photoelectric effect which is performed on the photoconductor cylinder. The total EP printing process is performed in 6 phases: charging, imaging, developing, ink transfer, ink fixing on the printing substrate and cleaning of photoconductor from ink rests. The basis of the process makes the photoconductor (photosensitive virtual printing form) which is by each printing repeatedly charged, imaged, developed and cleaned. During the charging process, the constantly high charge is generated on the photoconductor surface. It is selectively neutralized (decreased) by laser head activity which emits light of strictly defined wave length. The inks used in EP are mainly powder toners and much rarer liquid toners. Their basic characteristic is the negative charging which enables their acceptance for the positive photoconductor surface. The adhered toner on the photoconductor creates so called toner image which is transferred to the printing substrate after the activity of the electrostatic field is finished. The positive charged transfer corona is responsible for the more successful transfer of the greatest possible quantity of toner. At the very end of the printing process the photoreceptor is cleaned from the toner rests, while the toner is fixed on the printing form (fused) under the activity of high temperature. The toner is cooled down and it solidifies on the printing form (Majnaric, et al., 2005).

The IJ printing technology uses inks of a very low dynamic viscosity coefficient (η = 1-30 mPa·s), which is sprayed through tiny nozzles direct onto the printing substrate. Regarding the way of drops formation, IJ technology is divided in: continuous IJ (Binarne, Herz one) and IJ which forms a drop on demand (thermal IJ, piezo IJ, electrostatic IJ). Because of its quality and velocity the application of IJ enables different usages (printing on packaging, in-door application, out-door application, proof printing). In connection with this different formulations of inks are used in which the colorants and the colorant carriers can form the following ink types: Dye IJ inks, pigmented IJ inks, solvent IJ inks, UV IJ inks and IJ inks on vegetable basis.

3. EXPERIMENT

In this article we wanted to examine the quality of the monochromatic screen reproductions which were reproduced on momentarily most used digital printing machines. They are: Xerox 250, HP Indigo TS, Xerox DT 6135, OCE 2110 Vario, HP 9050, Canon IR 7105, Epson SP R2400, Epson SPRO 7000, Riso RZ 970 E, Heidelberg QM 46 DI. The influence of the uncoated printing substrates on the black-white reproduction, i.e. on the quality of the final printed products was analyzed. Three characteristic printing substrates were used for the experiment: wood-free offset paper (120 g/m^2 Arcoprint E.W.), photo-copier paper (80 g/m^2 Navigator) and the

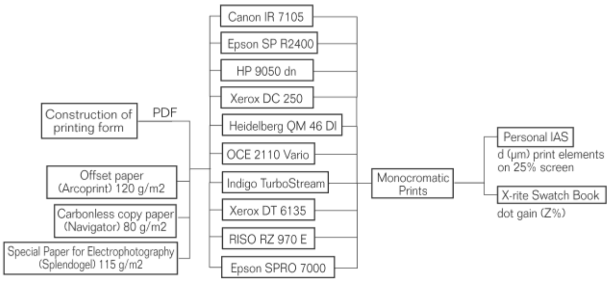

Figure 1. Schematic presentation of the experiment

paper made for the digital printing (115 g/m^2 Splendogel E.W.) For the experiment, the special achromatic printing form was constructed, which was saved in the standard PDF form. It contains 99 screen patches for creating the reproduction curves (in the range for 1 to 99% halftone value), textual microelements in positive and negative (from 1 to 14 pt), standardized achromatic illustration and positive and negative lines (standard width of 650 μm). By means of measuring elements X-rite DTP 41 the values of the optical inking density (D) were measured, from which the surface coverage (F_D) was calculated, i.e. dot gain (Z). With the device for image analysis (Personal IAS) the aberration of the screen element sizes (in the area of 25% halftone value) was determined, which depended directly on the type of the uncoated printing substrate.

4. RESULTS AND DISCUSSION

It is possible to measure the monochromatic quality of prints by densitometer, in which the uniformity of the step wedge printing was analyzed, whose values had to grow continuously. It can be expected that for the qualitative print there is the visible difference in the lightest areas (1-5% halftone value) as well as in the darkest areas (95-99% halftone value). In figures 2, 3, 4 and 5 the reproduction curves of the digital printing machines made on three uncoated printing substrates are presented.

On the analyzed reproduction curves the printing machine HP 9500 creates the following dot gains: Z_{10}=17%, Z_{50}=30,5%, Z_{90}=9,5% (Arcoprint), Z_{10}=13,5%, Z_{50}=25%, Z_{90}=9% (Navigator), Z_{10}=23%, Z_{50}=30,5%, Z_{90}=9,5% (Splendogel).

On the analyzed HP prints (areas of 10%, 50% and 90% halftone value) the greatest dot gain difference was on the prints obtained by printing the Splendogel and Navigator paper. It is characteristic that Arcoprint and Splendogel printing substrates do not influence the changes of the printed medium and high tonal values. Only the low tonal values have the change $Z_{10(S\text{-}A)}$=6%. The printing machine Xerox 250 forms the following dot gain values: Z_{10}=3,5%, Z_{50}=23%, Z_{90}=9,5% (Arcoprint), Z_{10}=-1%, Z_{50}=17,5%, Z_{90}=7% (Navigator), Z_{10}=4,5%, Z_{50}=30%, Z_{90}=9% (Splendogel). By changing the printing technology (from HP 9050 to Xerox 250) the prints with smaller dot gain were produced.

On the prints made on Arcoprint and Navigator the dot gain was decreased to Z_{50}=7,5%, while on prints made on Splendogel the dot gain was decreased for Z_{50}=0,5%. Such results are directly influenced by the addition of whitening agent in the paper. Arcoprint and Splendogel papers have more expressed optical dot gain (they were additionally bleached) in regard to the Navigator paper. The mechanical dot gain cannot fortunately be influenced, while the choice of the unbleached printing substrate can influence the optical dot gain, i.e. it can influence the decrease of the printed medium tonal areas.

On the reproduction curves for the printing machine Epson 2400, great dot gains are visible: Z_{10}=10%, Z_{50}=32,5%, Z_{90}=9% (Arcoprint), Z_{10}=9,5%, $Z_{50\%}$=33,5%, Z_{90}=10% (Navigator), Z_{10}=11,5%, Z_{50}=30,5%, Z_{90}=9% (Splendogel). It is characteristic for all three printing substrates that in the area of 85% halftone value they have their maximum. The tones between the halftone values of 85 and 99% are lost and these papers are not suitable for qualitative printing. Such behaviour is the result of the rough printing substrates and greater concentration of the applied black IJ ink.

Because of its great capillary absorbance, the paper absorbs greater tone quantity. In connection with this the smaller surface overflowing of ink appears which causes the closing of high halftone values. The printing machine Xerox 6135 creates the following dot gains: Z_{10}=9,5%, Z_{50}=18%, Z_{90}=8,5% (Arcoprint), Z_{10}=6%, Z_{50}=18%, Z_{90}=6,5% (Navigator), Z_{10}=6,5%, $Z_{50\%}$=20,5%, Z_{90}=7% (Splendogel).

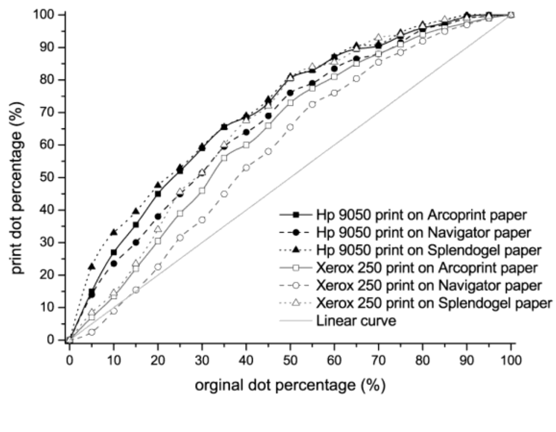

Figure 2. Reproduction curves of Xerox 250 and HP 9050 on Arcoprint, Navigator and Splendogel paper

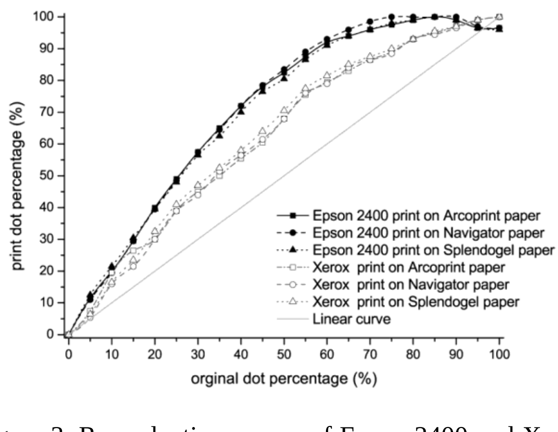

Figure 3. Reproduction curves of Epson 2400 and Xerox 6135 on Arcoprint, Navigator and Splendogel paper

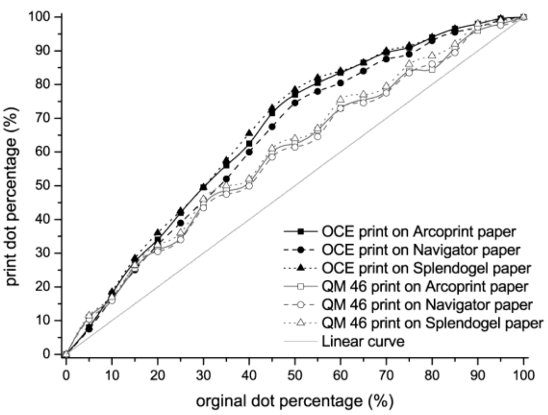

Figure 4. Reproduction curves of OCE 2110 Vario and QM 46 DI on Arcoprint, Navigator and Splendogel paper

By comparing the pigmented IJ ink (Epson 2400) and EP two component toner (Xerox 6135) great deviation in dot gain was noticed (IJ technology causes greater dot gain: Arco Z_{50}=14,5%, Nav Z_{50}=15,5%, Splen Z_{50}=10%).

With the EP printing machine OCE 2100 the reproduction curves were obtained in which the dot gain was much more expressed: Arco (Z_{10}=8%, Z_{50}=27%, Z_{90}=8%) Nav (Z_{10}=6,5%, Z_{50}= 25%, Z_{90}=7%) Splen (Z_{10}=8,5%, Z_{50}=28,5%, Z_{90}= 8%). Digital waterless offset QM 46 DI produced the reproduction curves of a snake-like form in which the dot gains were very homogeneous: Z_{10}=6,5%, Z_{50}=12,5%, Z_{90}=6% (Arcoprint) Z_{10}=6%, Z_{50}= 11,5%, Z_{90}=7% (Navigator) Z_{10}=7%, Z_{50}=14%, Z_{90}= 8% (Splendogel). By changing the printing technology (from OCE 2110 to QM 46 DI) the prints were made with great change in dot gain. According to the tested papers this difference is the following one: Arco Z_{50}= 14,5%, Nav Z_{50}= 13,5% and Splen Z_{50}= 16,5%.

For the printing machine Canon 7105 the snake-like form of the reproduction curves was characteristic. There was also great oscillation of Splendogel curve (Z_{10}=9,5%, Z_{50}= 19,5%, Z_{90}=6,5%), and smaller oscillations of Arcoprint curve (Z_{10}=2,5%, Z_{50}=10%, Z_{90}=6%) and Navigator curve (Z_{10}=3%, Z_{50}= 8,5%, Z_{90}= 4%).

The reproduction curves made with dye toner (Epson 7000) is characterized by the following dot gain: Z_{10}=5%, Z_{50}=20%, Z_{90}=8,5% (Arcoprint), Z_{10}=3%, Z_{50}=13%, Z_{90}=8% (Navigator), Z_{10}=6%, Z_{50}=22,5%, Z_{90}=9% (Splendogel). By analyzing the specific areas, it is visible that the changes of the printing substrates enable the minor changes in the reproduction of lighter and darker tones ($Z_{10(S-N)}$=3%, and $Z_{90(S-N)}$=1%) as well as greater changes in medium tones ($Z_{50(S-N)}$=12%). There is not critical area at 85% halftone value for all the three printing substrate. In this area they do not have their maximum and the darkest tones are printed with the determined difference. By changing the printing technology (from Canon 7105 to Epson 7000) the prints were made with the increased dot gain. This dot gain was: Z_{50}=10% (Arcoprint), Z_{50}=5,5% (Navigator) and Z_{50}=3% (Splendogel).

With the EP printing machine Indigo TS the reproduction curves were made, which mostly followed the linear reproduction curve. The lightest screen elements were not reproduced at all. The dot gains were mainly negative (the printing elements were smaller than the expected ones): Z_{10}= -10%, Z_{50}=-0,5%, Z_{90}=-1% (Arcoprint) Z_{10}=-9%, Z_{50}=-6,5%, Z_{90}=-2% (Navigator) Z_{10}=-10%, Z_{50}=0%, Z_{90}= 1% (Splendogel). For such form of the Indigo curves the software LUT (look up table) linear was responsible, which influenced the decrease of optical dot gain of the digital screen element during screening. In this way the size of the printed screen elements was directly influenced. The printing machine Riso RZ 970 produced up to then the highest analyzed dot gain values on Splendogel paper: Z_{10}=26%, Z_{50}=30%, Z_{90}=9,% (Arcoprint), Z_{10}=18%, Z_{50}=23%, Z_{90}=7,5% (Navigator), Z_{10}=14,5%, Z_{50}=20,5%, Z_{90}=6,5% (Splendogel). It is characteristic that the greatest dot gain was obtained on Arcoprint paper and the smallest one on Splendogel paper. Greater dot gain corresponds to greater quantity of the adhered toner, which means that the liquid Riso ink is more qualitative bonded to the rougher Arcoprint printing substrate. By comparing the liquid EP ink and watery oily toner great difference in the obtained dot gain was noticed. Riso printing technology realized greater dot gain for: Z_{50}=31,5% Arcoprint, Z_{50}=29,5% Navigator, Z_{50}=20,5% Splendogel.

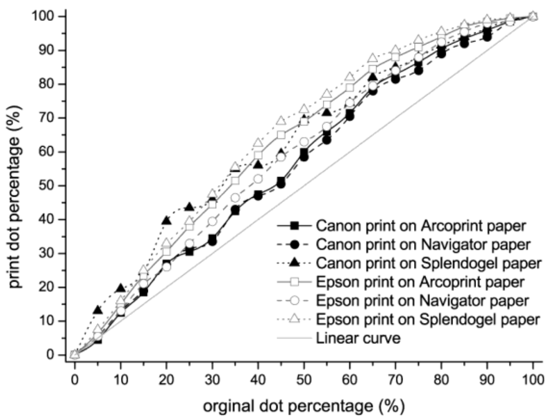

Figure 5. Reproduction curves of Canon 7105 and Epson 7000 on Arcoprint, Navigator and Splendogel paper

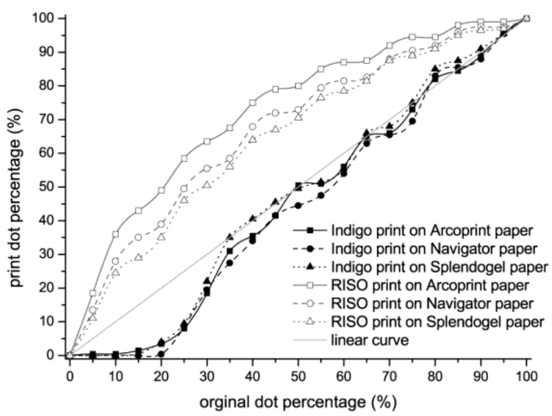

Figure 6. Reproduction curves of Indigo TS and Riso RZ970 on Arcoprint, Navigator and Splendogel paper

With the Image analysis system it is possible to analyze the printing elements, eliminating the optical dot gain. In 25% of halftone value the size of the reproduced halftone elements is not the same for the analyzed printing systems. The reason for that is in the construction of writing heads and the corresponding software RIPs, which are adapted to the type of the used black toner. The printing substrates influence the final version of the printed halftone elements. The smallest diameters of the printing elements on Arcoprint paper were created by: Epson 2400 (44,22 μm), Xerox 250 (45,34 μm), Indigo TS (56,76 μm), OCE (66,68 μm), Canon (80,3 μm), HP 9050 (85,15 μm), Xerox 6135 (97,49 μm), QM (98,46 μm), Epson 7000 (125,22 μm) and Riso (172,45 μm). On Navigator paper the following diameter values of the printed screen elements were generated by: Xerox 250 (46,64 μm), Indigo TS (49,39 μm), QM (58,67 μm), Epson 2400 (71,24 μm), HP 9050 (83,03 μm), Canon (84,99 μm), OCE (87,85 μm), Xerox 6135 (96,42 μm), , Epson 7000 (114,21 μm) and Riso (154,45 μm). On Splendogel paper the prints with the following values of screen elements were generated by: Epson 2400 (31,41 μm), Indigo TS (52,32 μm), Xerox 250 (61,82 μm), QM (74,97 μm), Canon (77,12 μm), HP 9050 (86,75 μm), Xerox 6135 (96,61 μm), OCE (104,99 μm), Epson 7000 (128,13 μm) and Riso (148,96 μm).

By changing substrate the greatest changes were in: IJ with pigmented ink ($\Delta d_{Epson2400}$=39,83 μm), waterless offset (Δd_{QM46DI}=39,79 μm) and EP with copy press system of toner pressing. (Δd_{OCE}=38,31 μm). The universal printing technique was EP based on two component toner and ElectroInk ($\Delta d_{Xerox\ 6135}$=1,07 μm; $\Delta d_{HP\ 9050}$=3,45 μm; Δd_{Indigo}=7,37 μm Δd_{Canon}=7,87 μm). After them the following ones were: IJ with dye ink ($\Delta d_{Epson7000}$=13,92 μm), EP with emulsion aggregation toner ($\Delta d_{Xerox250}$=16,48 μm) and digital screen printing (Δd_{Riso}=23,49 μm).

5. CONCLUSION

- On prints obtained with two component toner (HP 9050), the change of the printing substrate created maximal differences in dot gain: $Z_{10\%(S-N)}$=9,5%, $Z_{50(S-N)}$=5,5% and $Z_{90(S-N)}$=1%.
- On prints made on EP machine Xerox 250, the change of the surface processing resulted in greater changes: $Z_{10\ (S-N)}$=5,5%, $Z_{50\ (S-N)}$=12,5% and $Z_{90\ (S-N)}$=2%. This enabled perfect reproduction of dark tones whihc were not closed even in the darkest areas (above 90% halftone value).
- Epson 2400 enabled the minor changes in reproduction: $Z_{10\%(S-N)}$=2, $Z_{50\%(N-S)}$=3% and $Z_{90\%(N-SA)}$=1%.
- With EP prints made with two component toner (Xerox 6135), the printing substrate enabled small changes: $Z_{10\%(A-N)}$=3,5%, $Z_{50\%(S-AN)}$=2,5% and $Z_{90\%(A-N)}$=2%. Xerox 6135 enabled excellent reproduction (regular reproduction curve) in which a particular area between 10 and 20% halftone value was deformed.
- By intentional change of the printing substrate we did not influence the dot gain of OCE prints ($Z_{10(S-N)}$=2%, $Z_{50(S-N)}$=3,5% and $Z_{90(S-N)}$=1%).
- On prints obtained with offset ink the changes of the printing substrate caused small changes in the analyzed tones ($Z_{10(S-N)}$=1%, $Z_{50\ (S-N)}$=3,5% and $Z_{90(S-A)}$=2%).
- The printing substrates influenced considerably final prints on Canon $Z_{10\%(S-A)}$=7%, $Z_{50\%(S-A)}$=11% and $Z_{90(S-N)}$=2,5%. Splendogel paper enabled great dot gain in the area of lower tone values (10-50% halftone value).
- The change of the printing substrate in printing on Epson 7000, realized the minor changes in reproduction of light and dark tones ($Z_{10(S-N)}$=3%, and $Z_{90(S-N)}$=1%), and the greater ones in medium tones ($Z_{50(S-N)}$=12%).
- On Indigo prints, the printing substrate minimally influenced the final dot gains ($Z_{10(S-N)}$=1%, $Z_{50(S-N)}$=6,5% and $Z_{90(S-N)}$=3%). On Indigo the Splendogel printing substrate gave the highest quality.
- The change of the printing substrate enabled the important change in reproduction of the digital screen printing (Riso RZ 970): $Z_{10(A-S)}$=11,5%, $Z_{50(A-S)}$=9,5% and $Z_{90(A-S)}$=2,5%).
- Universal printing substrate for digital printing did not exist. The Arcoprint paper enabled approximately the smallest aberration within all analyzed printing substrates (Δd_{mid}=79,98 μm).
- For achieving dimensionally the smallest printing elements, the printing substrate Navigator had proved to be the most appropriate for the printing machines: Epson 7000, HP 9050, QM 46 DI, Indigo TS and Xerox 6135.
- Splendogel paper was recommended for achieving the maximal quality on Canon 7105 and Riso RZ 970 and Epsonu 2400, while the Arcoprint paper was recommended for the printing machines OCE 2110 and Xerox 250.
- Among all analyzed printing units, the smallest printed elements were formed by the EP machine Xerox 250 (Δd_{Arc}=45,34 μm, Δd_{Nav}=46,64 μm, Δd_{Arc}=61,82 μm), while the greatest printed elements were obtained with Riso (Δd_{Arc}=172,4 μm, Δd_{Nav}=154,4μm, Δd_{Arc}=148,9 μm

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