Mechanisms of Abnormal Dot Deformation in Gravure Printing

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Abstract

Gravure printability is often evaluated based on the visual appearance of the print. As long as all the gravure dots in the given image have the same shape - it may be solid dot or hollow dot (doughnut) - the print would look "smooth" and be considered acceptable. The problem starts when the image consists of dots of different shapes e.g. patch of solid dots next to the patch of irregular dot fragments or when some dots are missing. Such print would have poor visual appearance and can be called "mottled" or "rough". Abnormal deformation of dots is a very common problem in gravure printing on paper. Many dots are printed as incomplete dots (small fragments) of different shapes or irregularly shaped dots that have significantly larger diameter than the respective gravure cell e.g. horse shoe type irregular shape. Under certain circumstances the land area of the gravure cylinder may print instead of gravure cells – "negative" printing.

The purpose of this paper is to identify the root cause and mechanism(s) of abnormal dot deformation in gravure printing on paper. Gravure prints were analyzed using optical microscopy, scanning electron microscopy and optical profilometry. The analysis shows that abnormal dot deformation was observed only on paper – no dot deformation on plastic film. Calculations described in this paper and literature data on gravure printing shows that free ink spreading on paper is limited or impossible i.e. most lateral spreading takes part in the printing nip (at the entrance and an exit in the groove formed between the substrate and printing cylinder). The mechanism of abnormal dot deformation was proposed. Abnormal dot deformation appears to be due to the lateral flow of the ink into the gap formed between the paper and gravure cylinder in the printing nip (spontaneous capillary flow). The effect of paper surface

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topography on the gravure dot reproduction, ink transfer from the cell to the paper and some physicochemical phenomena responsible for the transfer are briefly discussed. Among different causes that may be responsible for poor printability the paper surface topography (waviness, presence of voids and bumps on the paper surface) appears to be a primary cause of “abnormal” dot deformation.

Introduction

The quality of the gravure print depends on the quality of the reproduction of the discrete dots. Very often, the printability is judged based on the visual appearance of the print (i.e. subjective method). Among the objective ways of printability evaluation, one can measure print density, gloss, number of missing dots, dot diameter, etc. (Popil 1996, Sjoblom 2004). In many instances gravure printability has been evaluated based on the number of skipped dots. Snowflaking (skipped dots) is a very common print defect observed in the gravure printing. It is well known from the literature (Antoine 1997, Hannson 2000, Preston 2006) that snowflaking is mostly due to the paper surface topography (presence of bumps, voids and protruding cellulose fibers and thus lack of direct contact of some gravure cells with paper surface). The population of skipped dots depends on the gravure cell size, the size and height of the paper bumps, size and depth of depressions or protruding cellulose fibers as well as the paper compressibility (Antoine 1997, Lorusso 1999, Kai 2004). Physical contact between ink and paper is critical for effective ink transfer. Gravure printing is especially sensitive to the paper flatness as in the nip compressible paper meets with a non-compressible and non-deformable metal gravure cylinder – see Fig. 1. For the other printing processes shown in Fig. 1 a good contact between paper and printing medium (plate or blanket) can be achieved more easily because the paper meets in the nip compressible and deformable flexo plate or offset blanket.

For a long time, paper surface roughness has been used as the parameter to predict printability and the tendency for missing dots. However, good correlation has not been observed between the surface roughness and skipped dots (Lorusso 1999, Picollet 1998). Roughness alone is not adequate to characterize paper surface topography. Topography of paper surface is a three-dimensional measure of surface irregularities. The surface can be rough, smooth, wavy or bumpy depending on the magnitude and spacing of the peaks and valleys. Roughness relates to closely spaced irregularities (the distance is much smaller than the size of the gravure cell or printing dot) and does not characterize the surface flatness. Waves, voids and bumps are larger surface features and they can be of the same size or larger than the gravure cells. Roughness is super-imposed on the waviness, bumps and voids. A gravure print may be free of print defects when printed on the rough (spacing between the peaks much smaller than the gravure cell size) but flat surface. On the other hand poor quality print can be obtained during printing on a smooth surface that is bumpy and contains voids. Therefore, the conventional roughness parameters are not good predictors of printability as they are insensitive to the surface feature spacing (Sprycha 2006, Zecchino, 2003). As mentioned above, the flatness of paper surface is a critical factor in achieving good printability in gravure printing (no skipped dots - no snowflaking). Any deviation from the surface flatness e.g. waviness, bumps or depressions, can contribute to the rough printing and skipped dots.

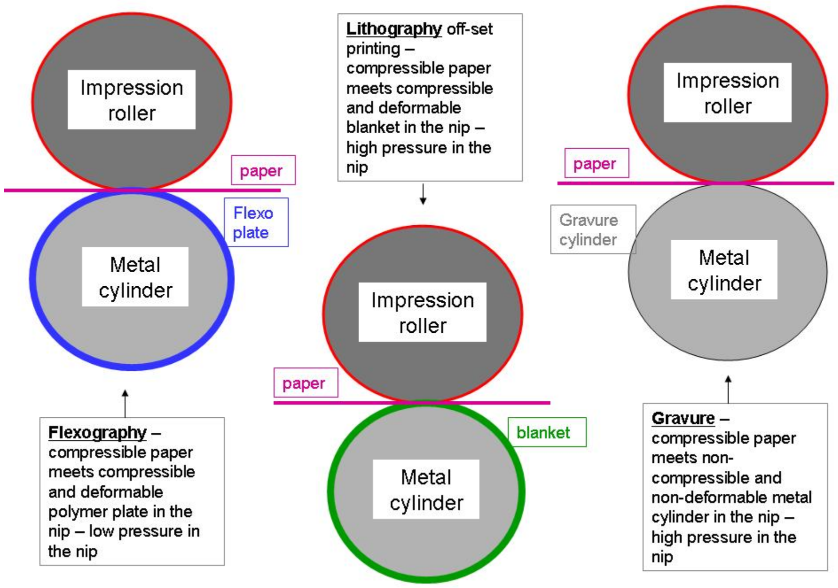

Fig. 1. Schematic diagram of different printing techniques.

It has been shown in a number of previous publications (Antoine 1997, Popil 1996, Picollet 1998) that paper quality is the most important factor that affects gravure printability. The type of filler used, manufacturing process of paper, coating and pore structure, surface topography, surface properties of paper, compressibility etc. have a paramount effect on ink-paper interactions and quality of dot reproduction. As long as all the gravure dots in the given image have the same shape - it may be solid dot or hollow dot (doughnut) - the print would look “smooth” and be considered acceptable. When the image consists of dots of different shapes e.g. patch of solid dots next to the patch of irregular dot fragments such print would have poor appearance and can be called “mottled” or “rough”. Besides missing dots, the deformation of gravure dots is another important factor that has a negative effect on printability.

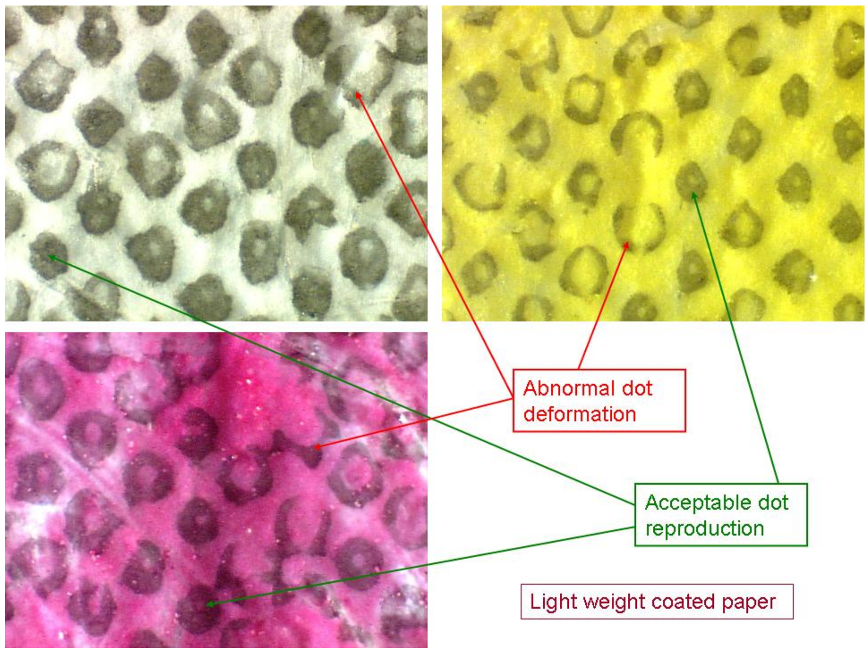

Fig.2. Photomicrographs of gravure prints – note the shape of the abnormally deformed dots printed on paper.

The abnormal deformation of dots is a phenomenon that can manifest itself in gravure printing in several ways. The dots can be printed as incomplete dots (small fragments) of different shapes or irregularly shaped dots that have significantly larger diameter than the respective gravure cell e.g. horse shoe type irregular shape – see Fig. 2. Under certain circumstances the land area of the gravure cylinder may print instead of gravure cells – "negative" printing – Fig. 3. To the best of our knowledge, the root cause of the abnormal dot deformation has not been identified so far.

The purpose of this paper is to identify the root cause and describe plausible mechanism(s) of abnormal dot deformation in gravure printing. Gravure prints were analyzed using optical microscopy, scanning electron microscopy and optical profilometry. The effect of paper surface topography on ink transfer from the cell to the paper and some physicochemical phenomena responsible for the transfer and dot reproduction are discussed. The comparison of printability and identification of the root cause of print defects may be difficult and confusing due to a large number of variables involved (prints might originate from

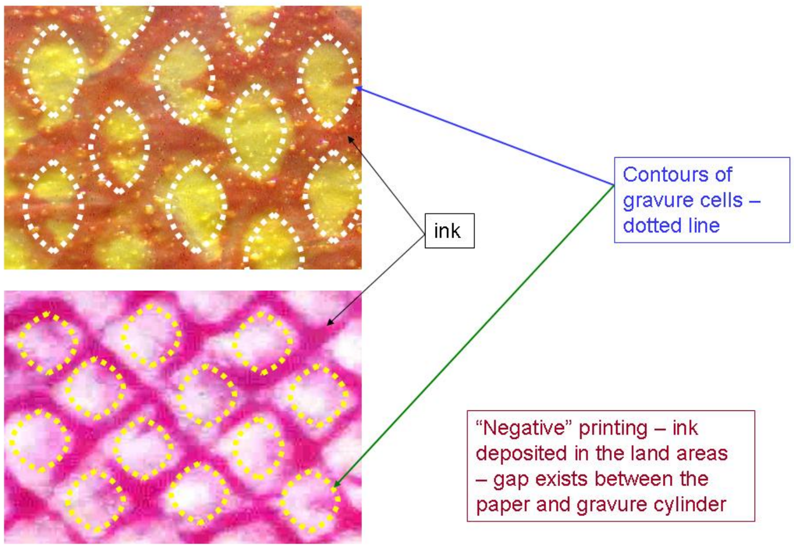

Fig. 3. Photomicrograph of "negative" print – land area of the cylinder print instead of the gravure cells (gap formed between the paper surface and gravure cylinder).

different printers, be printed on different substrates at different press conditions, using different inks, etc.). Even so called "the same" conditions may in fact be different. Therefore, in this paper, the print quality was evaluated based on the analysis of the reproduction of discrete dots of the same print. All the variables (paper compressibility, ink properties, press conditions, temperature, pressure, etc.) can be eliminated in this way.

Analysis of Gravure Prints

Figures 4-6 show examples of photomicrographs of gravure prints on different papers and a plastic film. As shown the fidelity of the gravure dot reproduction varied significantly depending on the quality of paper. Even on a high quality paper (heavy weight coated) most of the dots were slightly

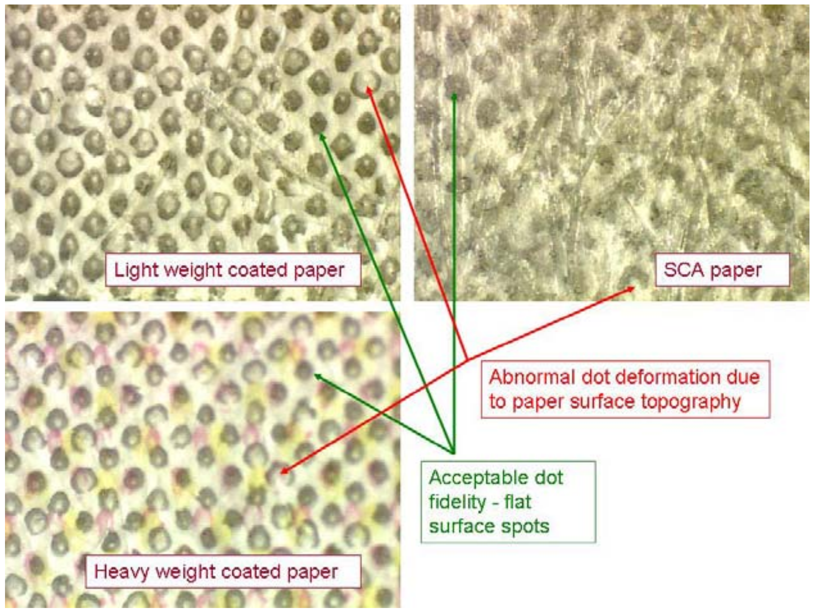

Fig. 4. Photomicrographs of gravure prints on different papers – note the shape of the dots (both high fidelity and abnormally deformed dots can be seen).

deformed ("doughnut" shape) – see Fig. 4. On a smooth and flat surface of a plastic film – Fig. 6 – poor dot reproduction was observed only for small gravure cells - the dots appeared also as "doughnuts". This may be due to two different factors: 1) the volume of ink withdrawn from the cell by the ESA (Gravure 1991) and the ink flow into the groove formed in the nip between the substrate and the cylinder surface (Sprycha 1997) is significant compared to the total cell volume and causes substantial ink meniscus deformation – deep concave meniscus (small curvature radius) and for 2) ink may dry too fast so that the increasing ink viscosity can affect ink transfer. Therefore, ink is essentially transferred to the substrate mostly along the cell perimeter and the dot formed takes on a "doughnut" shape – see Fig. 6. With increasing cell size and volume, the ink meniscus deformation would become less. Thus, the transition of dots shape from the doughnuts to the solid dots can be observed as in Fig. 6. As quality of the substrate decreases (shifting from the flat surface of plastic film to the paper surface that contains voids and bumps of varying size) the quality of gravure prints also decreases – see the photomicrographs in Figs 2-6. The doughnut shape of the gravure dots may result from the basics of the gravure printing process (Bery 1985, Sprycha 1997). However, acceptable doughnut dots may be only slightly larger (deformed) than the corresponding gravure cells. Irregularly shaped dots having a diameter significantly larger than

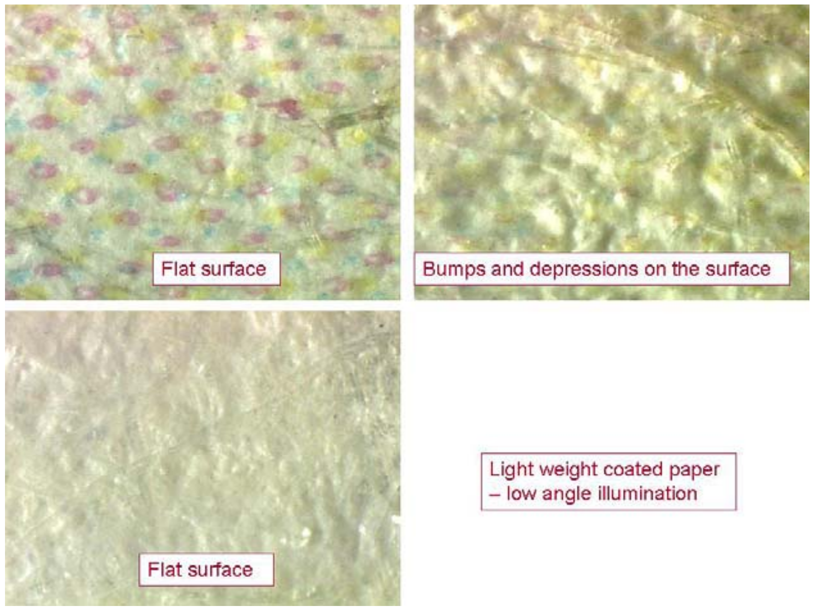

Fig. 5. Photomicrographs of coated paper (flat surface) and gravure prints on flat and bumpy paper surface at low angle illumination – note poor ink transfer on bumpy paper (missing dots, fragments of dots).

the respective gravure cells (abnormal dots) have negative effect on print appearance (rough printing) – Fig. 2. Such dots can be formed as a result of spontaneous and un-controlled flow of ink outside of the cell area. Ink can flow spontaneously outside of the cell only when the cell perimeter is not in intimate contact with paper surface (gap). This can happen when the paper surface is not flat. Paper compressibility can accommodate some surface irregularities. However, it has been shown that depressions deeper than 0.5 micrometers under zero load (relaxed paper surface) were not smoothed by the pressure in the printing nip (Preston 2006).

The following factors that affect dot reproduction can be considered as primary ones (Bery 1985, Gravure 1991, Kunz 1975, Joshi 2005, Popil 1996, Serafano 1999, Sjoblom 2004):

<u>Paper related factors:</u>

1. paper surface topography (presence of voids and bumps)
2. flatness of paper surface (direct contact between the gravure cylinder and paper surfaces)
3. paper compressibility and paper surface deformability

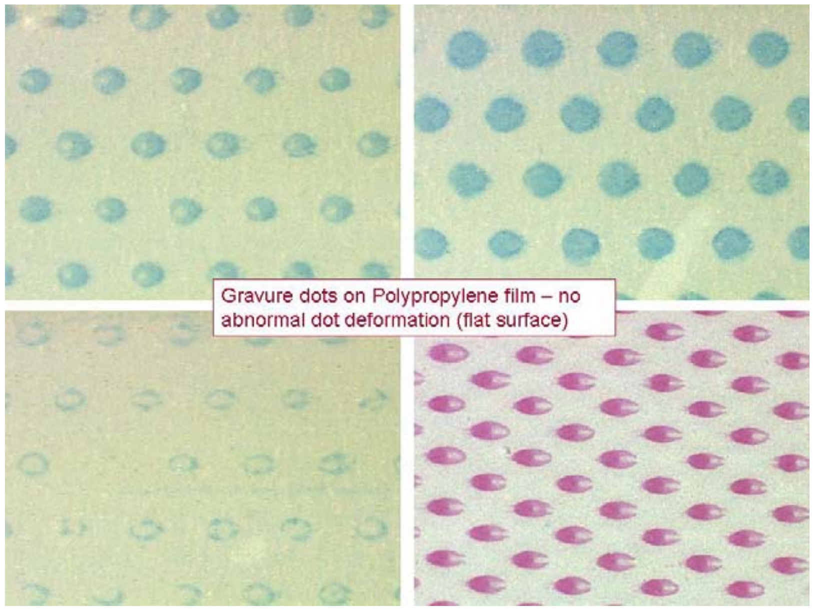

Fig. 6. Photomicrographs of gravure prints on plastic film (three different tonal areas of cyan and one tonal area of magenta) – note the lack of abnormal dot deformation.

4. paper absorptivity

Ink related factors:

1. ink viscosity and rheological properties
2. temperature (affects surface tension, viscosity and rheology)
3. surface energy balance between the ink, paper and the gravure cylinder

Press and process related factors:

1. electrostatic assist (ESA)
2. pressure in the printing nip
3. gravure cylinder roughness
4. cell size and geometry
5. printing speed
6. hardness of backing cylinder

As the analysis of the quality of the gravure dot reproduction has been performed on the same sample of the print, any differences in the fidelity between the discrete dots can be explained only by the local differences in the properties of the substrate. One can expect differences in printability between different grades of paper, as paper surfaces differ significantly regarding surface topography – e.g. uncoated paper vs. coated paper – see Figs 7-10. The surface

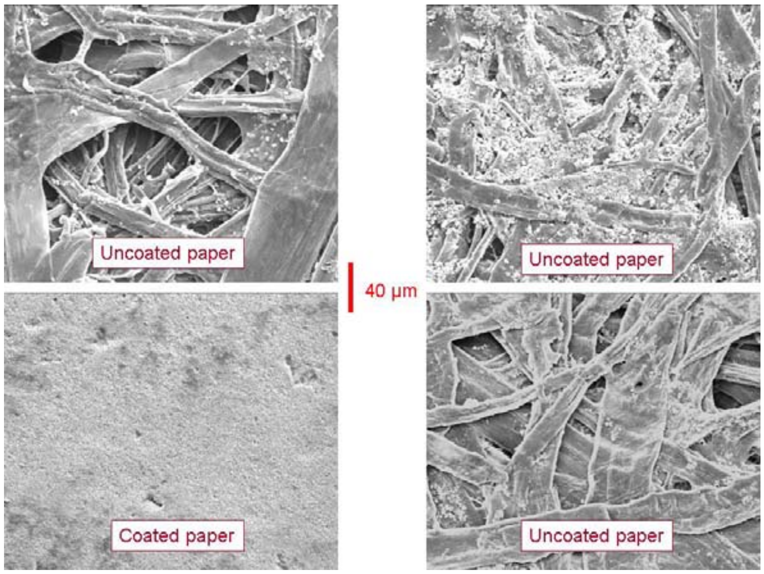

Fig. 7. The SEM images of paper surface – note the difference in surface topography.

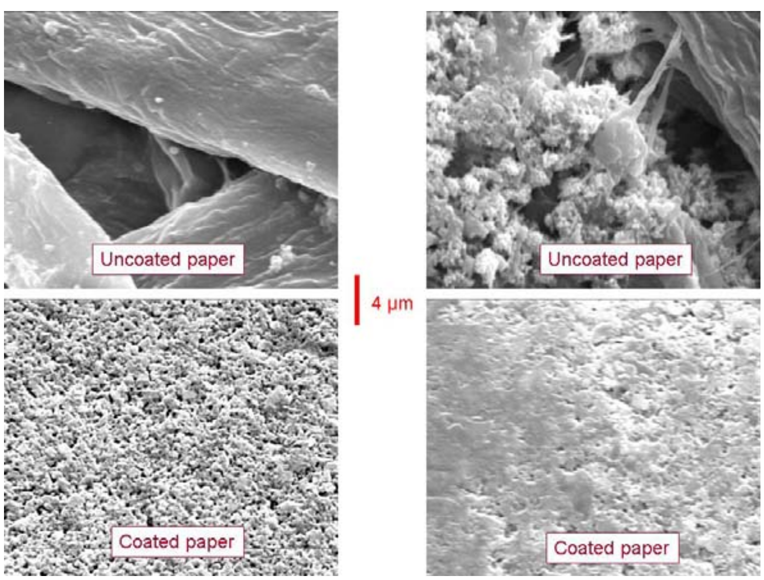

Fig. 8. The SEM images of paper surface – note the difference in surface topography.

irregularities of uncoated papers can be reduced by a paper coating. This coating eliminates large pores present in the uncoated papers (Figs 7-8) but it may still result in a flat or bumpy surface (Figs 9-10).

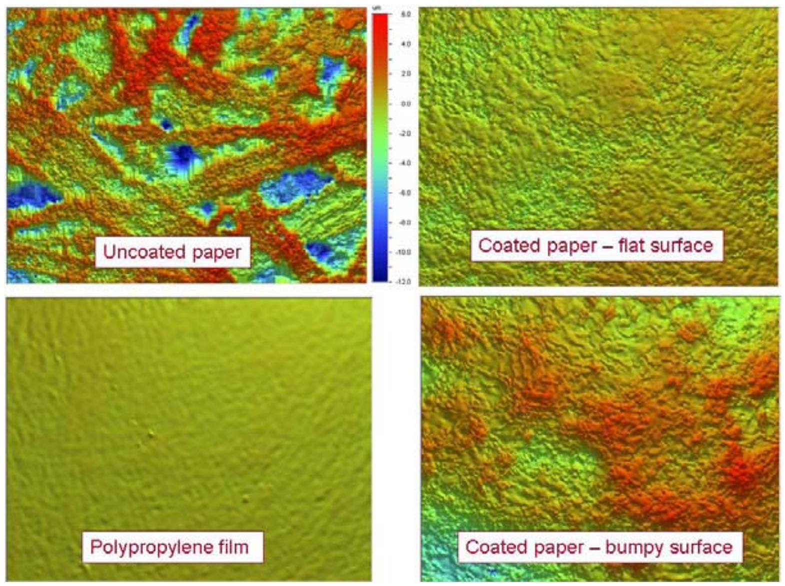

Fig. 9. Optical profilometry – 3D images (top view) of plastic film and paper surfaces – the same scale – note the surface topography of the samples.

To achieve the best ink transfer from the gravure cell to the substrate and maintain high dot fidelity, the entire perimeter of the gravure cell must be in direct contact with the substrate surface. As the metal gravure cylinder surface is not deformable, the flatness of the substrate is a critical factor in achieving efficient ink transfer and good dot reproduction. The mechanism of ink transfer to the smooth and flat surface is illustrated in Fig. 11. An example photomicrograph of gravure print on smooth and flat surface (plastic film - R_a~0.05μm) is shown in Fig. 6. It is reasonable to assume that high fidelity dots presented in Figs 2, 4-5 are also printed in the spots that had smooth and flat surface. High fidelity gravure dots may be solid dot or have a "doughnut" shape depending on the cell size, ink viscosity, efficiency of ESA, etc. but can be only slightly larger than the respective gravure cell.

For the plastic film surface which is smooth and flat, the problem of abnormal gravure dots deformation practically does not exist. Paper surfaces are much rougher and microscopically less flat than the surface of plastic films – e.g. average roughness parameter R_a for coated papers is ~ 1μm and the surface may have depressions and bumps – see Figs 4-5 and 9-10. Thus, the prospect for achieving the most intimate contact between the gravure cell and paper is expected to be much more difficult. If, for instance, the size of a deep surface depression is significantly larger than the size of gravure cell there may be no physical contact between the cell and paper leading to no ink transfer (missing dot). Between those two extremes – perfect contact and no contact of gravure cell with the paper surface there are numerous intermediate states which may result in the gravure dot deformation being dictated by the local paper surface topography. If the entire cell perimeter is not in direct contact with paper surface but the deformed ink meniscus can touch the paper surface in the nip then, the ink from the cell can flow to the gap formed between the paper surface and land area of the cylinder. This flow would tend to transfer the ink outside of the cell area. The shape of the resulting "dot" would depend on the local topography of paper. If surface topography allows for gap formation between the entire land areas of the cylinder, then the land area would print instead of the gravure cells which is the basis of negative printing (Bery 1985) – see Fig. 3.

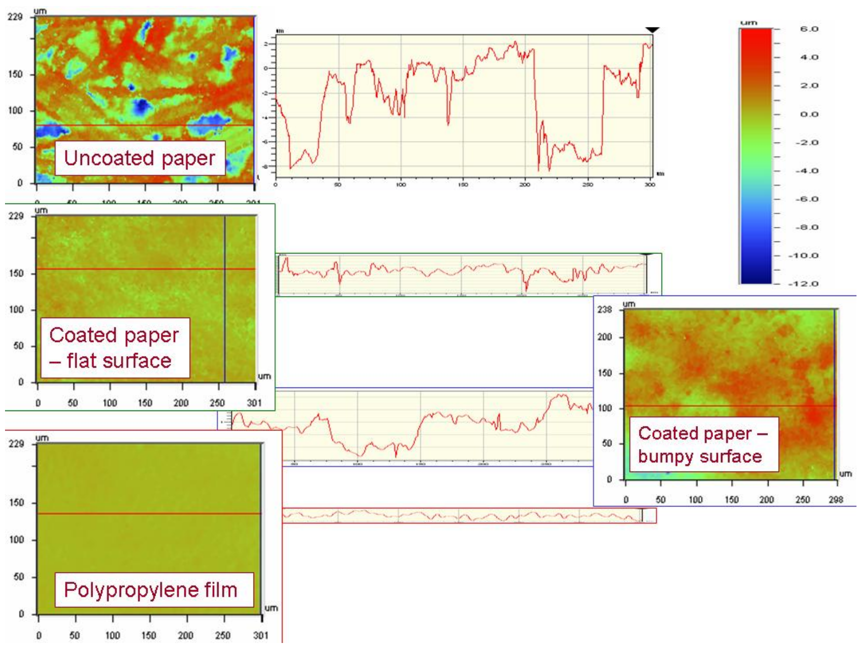

Fig. 10. Optical profilometry – 2D images and virtual cross-sections of plastic film and paper surfaces – the same scale – note the size of the bumps and voids of the samples.

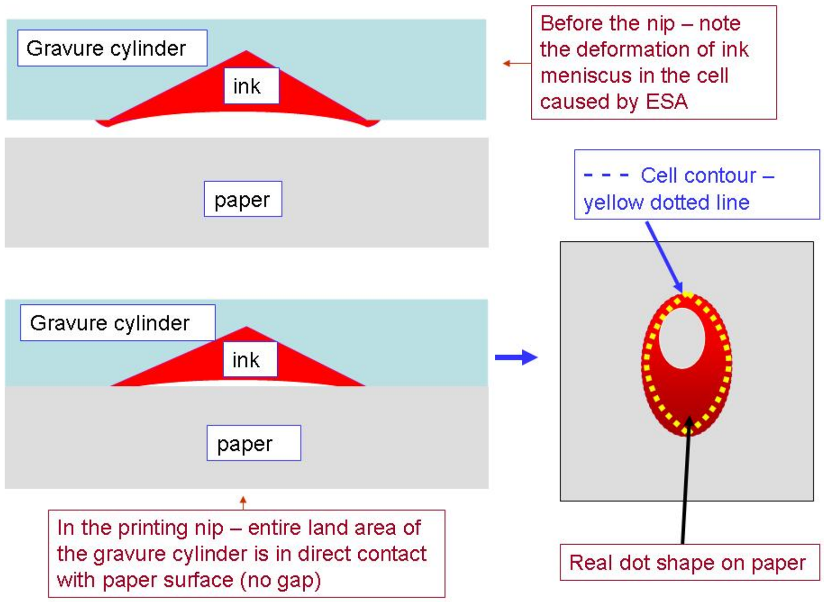

Fig. 11. Schematic diagram of ink transfer from the gravure cell to the flat surface.

Theoretically, the gravure dot can be larger than the respective cell if the ink can spread freely or it is forced to spread on the surface of the substrate. One of the factors contributing to the dot gain is spreading of the ink in the groove formed between the paper and gravure cylinder at the entrance and exit of the nip (Sprycha 1997). Due to a very short "life time" of such a groove (at the speed of 3000 fpm the estimated time is less than ~10μs), the distance of lateral flow of ink would be no more than a few micrometers. Therefore, this phenomenon is unlikely to be responsible for the abnormal dot deformation.

The free spreading of ink deposited on paper in the nip can take place only when its contact angle is greater than the value of the equilibrium contact angle for that system. The angle (Θ) of the diamond styli used for the gravure cylinder engraving ranges from 110° to 140° (Gravure 1991). Assuming that: the stylus engraving angle $\Theta = 120°$; the gravure cell has an inverted conical shape (as a first approximation - for the mathematical simplicity); a cell radius $r = 25$ micrometers; 50% of ink is transferred to the paper (Jeske 1990) and the ink deposited on paper has spherical cap shape (see Figs 12-13), one can calculate the value of the contact angle (θ) of ink deposited on paper. The volume of the ink in the cell (V_H) can be expressed as:

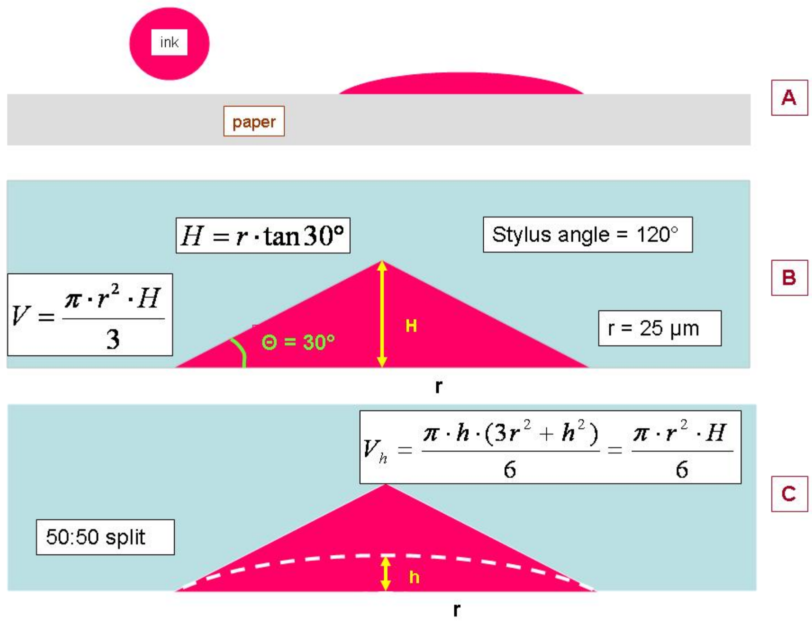

Fig. 12. Free ink spreading (droplet of ink spreads on the surface) vs. gravure printing (ink transferred from the cell of a given size) – schematic diagram: A) initial and final stages of droplet spreading; B) gravure cell – conical shape; C) ink below the dotted line is transferred onto paper.

$$V_H = \frac{\pi \cdot r^3 \cdot \tan 30°}{3} \tag{1}$$

Based on the above assumptions the volume of the ink of the spherical cap (V_h) is:

$$V_h = \frac{\pi \cdot r^3 \cdot \tan 30°}{6} = \frac{\pi \cdot h \cdot \left(3r^2 + h^2\right)}{6} = \frac{\pi \cdot h^2 (3R - h)}{3} \tag{2}$$

where: "h" is the height of the cap and "R" is the radius of the cap. Knowing the volume of the spherical cap one can calculate "h" and "R" from Eq. (2) and then the value of contact angle θ of the ink deposited on paper – see Fig. 13:

$$\cos\theta = \frac{R - h}{R} \tag{3}$$

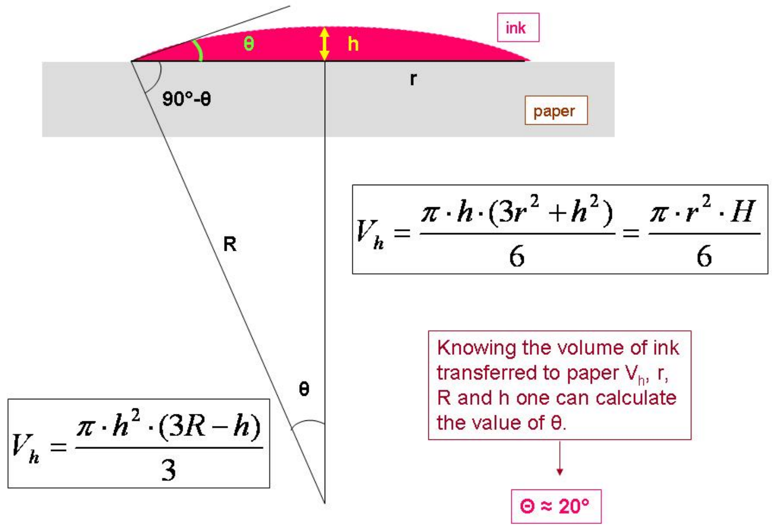

Fig. 13. Schematic diagram – calculations of contact angle (θ) of ink transferred from the gravure cell onto paper surface – see the text for explanation.

The calculated value of contact angle (θ ~ 20°) is the same (Sprycha 1994) or lower (Serafano 1999) than that measured for the gravure ink or toluene varnish on paper, respectively. Thus, free spreading of ink on paper is unlikely (or very limited). Pressroom experience confirms such a conclusion - high fidelity dots are usually only slightly larger than the respective cells. Thus, one has to assume no free ink spreading on paper but another mechanism is responsible for the abnormal dot deformation.

This mechanism that causes abnormal dot deformation is presented schematically in Fig.14. If the paper surface is locally not flat (e.g. depression) the gap can be formed between the paper surface and gravure cylinder. The ESA and centrifugal forces will cause ink meniscus deformation so that the ink is above the cylinder surface along the cell perimeter (Gravure 1991, Bery 1985). In the printing nip, the deformed meniscus of the ink may touch the paper surface and ink can be "sucked" to the gap (flat capillary). If the deformed meniscus of the ink touches the paper along the entire cell perimeter the resulting deformed dot would have "circular" shape depending on the local paper surface topography. On the other hand, if there is no contact of the ink with paper surface no ink would be transferred to paper and one would observe a missing dot. When deformed ink meniscus is only in partial contact with paper surface the fragment of the gravure dot would be printed on paper. The shape of

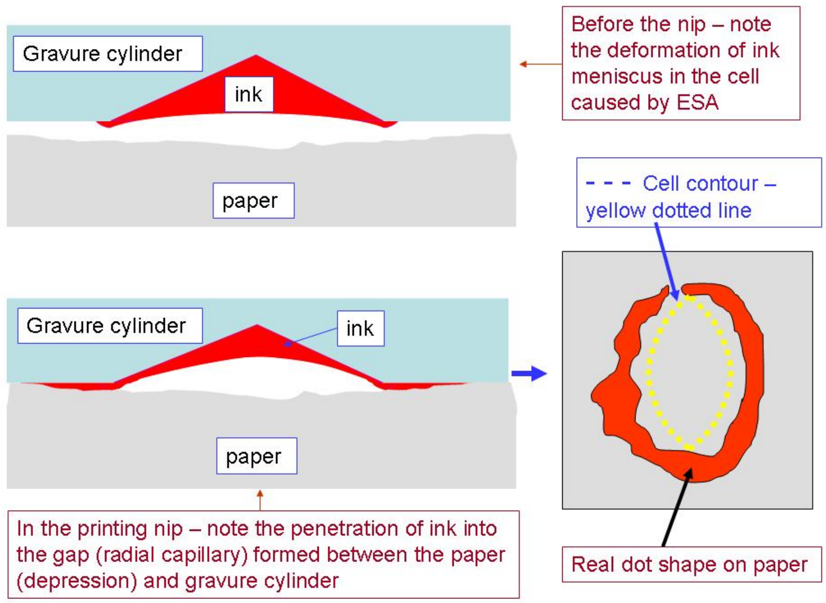

Fig. 14. Schematic diagram of ink transfer from the gravure cell into the depression in the paper surface – abnormal dot deformation – see text for more information.

such fragment would again depend on the local paper surface topography – see e.g. Fig. 2.

The ink from the gravure cell will flow spontaneously into the gap (capillary action). The criterion for the spontaneous penetration of liquid into the capillary is that $\theta<90°$ (Marmur 1992). This condition is met by the ink on paper – contact angle $\theta \sim 20°$ (Sprycha 1994). Prediction of ink behavior in the printing nip upon contact with paper surface is extremely difficult. In general, the mathematical modeling of liquid penetration into a capillary is very complicated for an irregularly shaped capillary or system of capillaries of different sizes (Bousfield 2004, Hyvaluoma 2006) and is outside of the scope of this paper. Therefore, to estimate the rate of penetration of ink into the gap formed between the gravure cylinder and paper in the printing nip the considerations presented in this paper were limited to the simple models either penetration from the unlimited reservoir into the cylindrical capillary of constant radius or radial capillary of a constant geometry (two parallel plates separated by distance “d”) (Danino 1994, Marmur 1988, Marmur 1992).

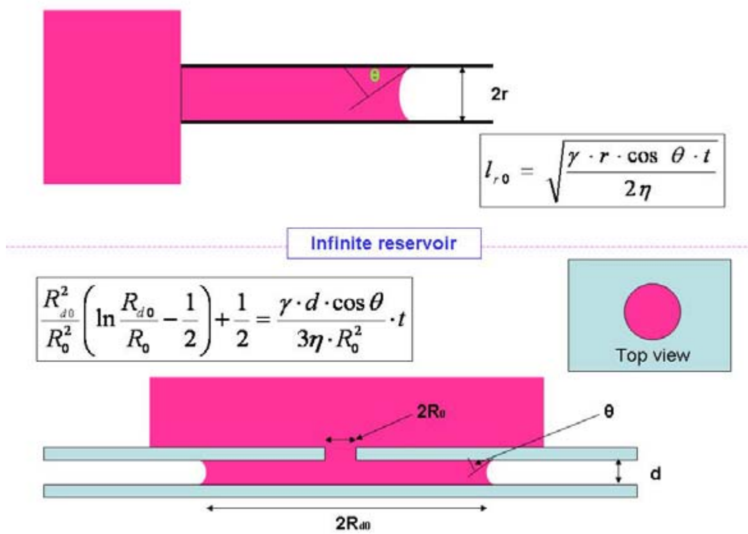

Fig. 15. Schematic diagram of liquid penetration from the unlimited reservoir into the horizontal cylindrical capillary and radial capillary – see text for explanation.

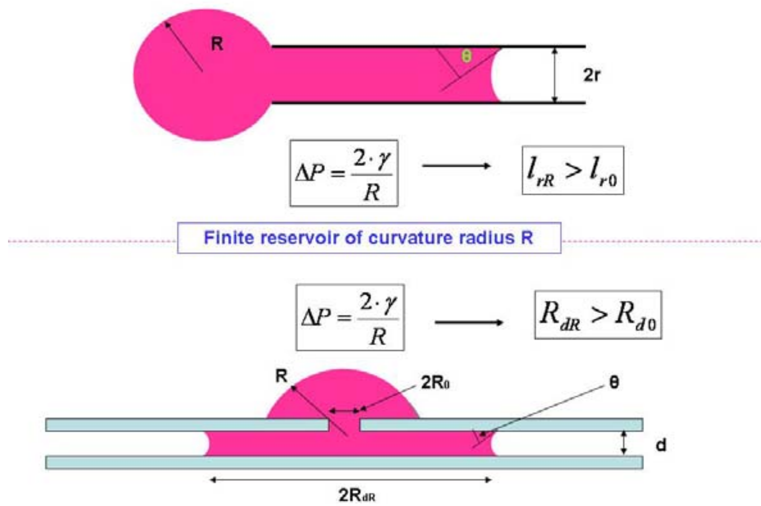

Fig. 16. Schematic diagram of liquid penetration from the limited reservoir into the horizontal cylindrical capillary and radial capillary – see text for explanation.

The two above models are schematically presented in Figs 15-17. The distance of penetration of liquid in the horizontal cylindrical capillary from the unlimited reservoir (l_{r0}) as a function of time (t) can be expressed by Eq. (4).

$$l_{r0} = \sqrt{\frac{\gamma \cdot r \cdot \cos\theta \cdot t}{2\eta}} \tag{4}$$

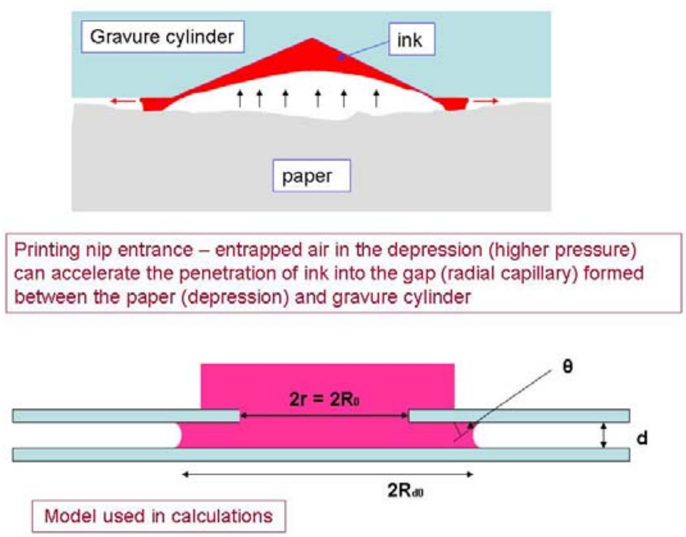

Fig. 17. Schematic diagram of ink transfer from the gravure cell into the depression on the paper surface – abnormal dot deformation due to capillary penetration and entrapped air – see text for explanation.

where: γ is the surface tension of the ink and η is viscosity of the ink. This is the well known Lucas-Washburn Equation (Marmur 1992). The flat gap formed between the paper and gravure cylinder in the nip has irregular non-cylindrical shape. Such a gap may be better described by the radial capillary consisting of two parallel plates. The Equation describing the radius of penetration of ink from the infinite reservoir into the radial capillary as a function of time (Danino 1994) is presented below (see also Figs 15-17):

$$\frac{R_{d0}^2}{R_0^2}\left(\ln\frac{R_{d0}}{R_0} - \frac{1}{2}\right) + \frac{1}{2} = \frac{\gamma \cdot d \cdot \cos\theta}{3\eta \cdot R_0^2} \cdot t \tag{5}$$

where: R_{d0} is the radius of the ink in the gap; R_0 is the radius of the hole through which the ink penetrates into the gap (radius of the gravure cell – see Fig. 17) and d is the distance between two parallel plates (surface of paper and surface of gravure cylinder).

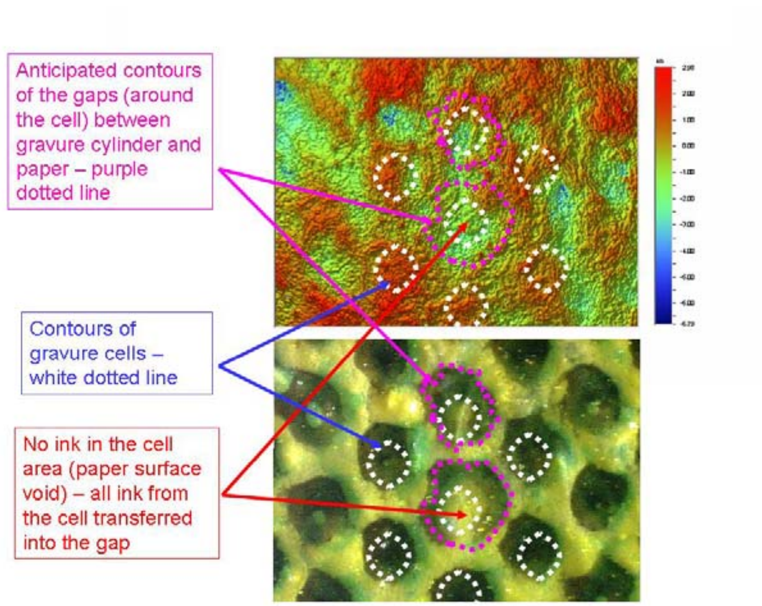

Fig. 18. Photomicrograph and 3D image of the same area of the gravure print – note that high fidelity dots were printed in the flat spots of paper (elevated area) and deformed dots in the areas that showed deviations from flatness.

Equations (4) and (5) were used to estimate the rate of penetration of ink in the gap formed between the paper and gravure cylinder in the printing nip. Calculations for the cylindrical capillary, Eq. (4), were made assuming: ink viscosity η=10 mPas; surface tension of the ink γ=35 mN/m; contact angle θ=20° radius of the capillary r=1 μm and the dwelling time t = 1 millisecond. This dwelling time corresponds to the press speed ~3000 fpm. The same parameters were used for the radial capillary, Eq. (5), assuming ink transfer from the conical cell of the radius r=25 μm and separation distance d=2μm – see the model presented in Fig. 17 (it was assumed that $r=R_0$). The calculated distance of penetration of the ink in the cylindrical capillary was ~40 μm. In the radial capillary that distance [increase in the dot radius (R_{dR}-R_{d0})] was ~30 μm.

The rate of penetration calculated using Eqs (4) and (5) - unlimited ink reservoir - is in fact the minimal rate. Liquid from the finite reservoir of the curvature radius R, penetrates faster than that from the unlimited reservoir (R=∞) as an additional pressure due to the surface curvature enhances the penetration (Danino 1994, Marmur 1988, Marmur 1992) – see Fig. 16. This pressure (ΔP) depends on the radius of the reservoir (R) and surface tension of the liquid (γ) - see Eq. (6) - (Marmur 1992):

$$\Delta P = \frac{2 \cdot \gamma}{R} \tag{6}$$

Moreover, compression of entrapped air in paper voids (depressions) can accelerate ink penetration into the gap – see schematic illustration in Fig. 17. Thus, the real distance of penetration is at least equal to or higher than that calculated above - $l_{rR}>l_{r0}$ and $R_{dR}>R_{d0}$. The calculated data showed that during the dwelling time (~1 millisecond) ink can easily penetrate into the gap the distance that is of the same size as the small gravure cell. This supports the mechanism proposed for the abnormal dot deformation and presented in Fig. 14.

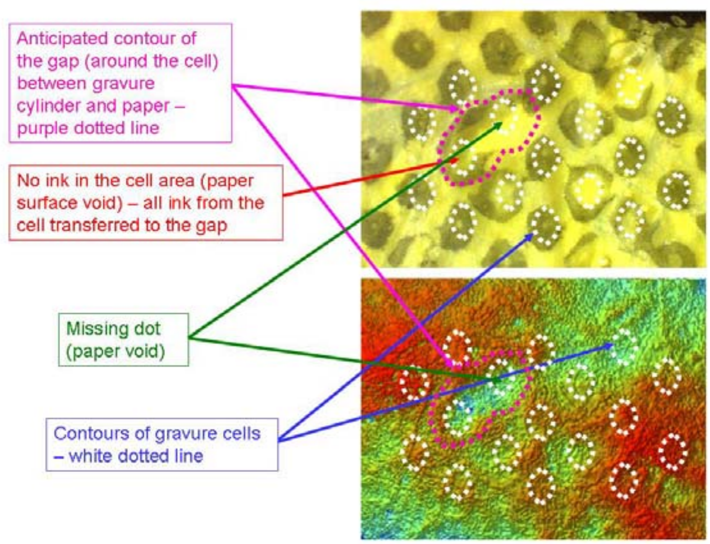

Fig. 19. Photomicrograph and 3D image of the same area of the gravure print – note that high fidelity dots were printed in the flat spots of paper (elevated area) and deformed dots in the areas that showed deviations from flatness.

The validity of this mechanism was also further supported by optical microscopy and optical profilometry (photomicrographs and 3D images of the same area of the prints) – see examples in Figs 18-19. The topography of paper surface presented in Figs 18-19 (relaxed surfaces – no load) may be slightly different than that in the nip (under high pressure) due to the paper compressibility (Wanske 2006). However, as shown previously (Preston 2006) the large and deep depressions (the depth of the depression where abnormal dot deformation was observed in Figs 18 and 19 was ~ 2-3μm) cannot be eliminated in the printing nip. As seen good dot reproduction was observed in the elevated flat areas of the print. Gravure dots printed in the areas that were not flat showed varying degrees of deformation depending on the local surface topography of paper. The effect of surface topography on print quality is schematically presented in Fig. 20. Usually, paper compressibility is not able to eliminate all surface imperfections. Therefore, problems with dot reproduction can be observed even on "high quality" coated papers (Fig. 4). The extent of dot deformation depends on the surface topography of paper (flatness of the surface).

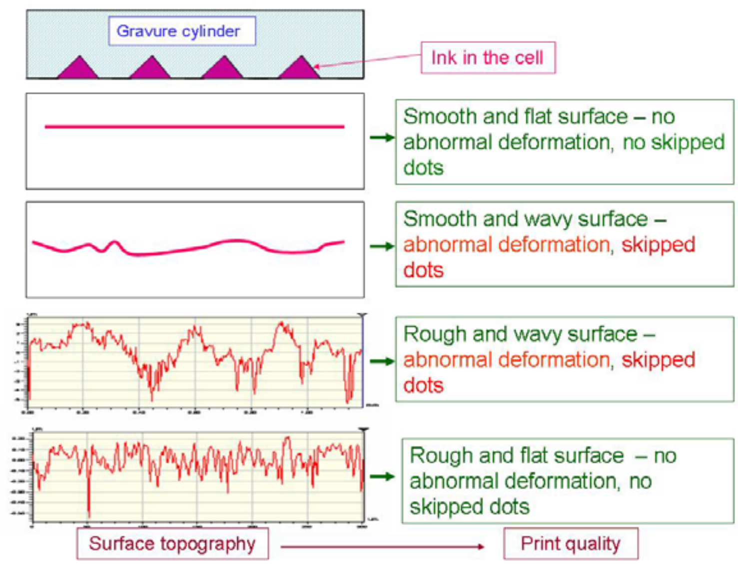

Fig. 20. Effect of surface topography on the gravure printability (dot reproduction) - schematic diagram.

It is well known that printability issues are the most obvious for small cells – generally, the smaller the cell the more problems with dot fidelity. Absorptivity of paper also plays a very important role in the dot reproduction (Picollet 1998). In the printing nip, two concurrent processes start simultaneously – the absorption of ink by paper and ink spreading [into the groove formed between the paper and gravure cylinder at the entrance and the exit from the nip (Sprycha 1997) and the penetration of ink into the gap that may be formed between the printing cylinder and paper]. The final dot shape and size is the net result of competition between absorption and spreading (penetration). For a given system the more absorptive the paper the faster the ink (or solvent) absorption and less ink penetration into the gap is observed (less abnormal deformation). For less absorptive substrates ink stays fluid on the surface for a longer time and can penetrate further to the gap (more abnormal deformation).

Another factor that can affect gravure dot deformation is pressure in the nip. For a given screen the "radial gap" around a given gravure cell can be formed easier in the light tones (small cell size) than in the larger size cells area. The pressure in the printing nip is usually expressed in pounds per linear inch (pli). One has to remember that the "local" pressure may vary significantly depending on the cell size. Assuming constant pli value in the nip and knowing that the pressure is exerted mostly by the land area of the cylinder the real local pressure for small cells would be smaller (wide land area – less pressure per area unit) than that in the larger cell area (narrow land area – higher pressure per unit area). Thus, under higher local pressure (larger cells) the paper in the nip is more compressed so that the chances for formation of gaps (radial capillaries) around the cells (responsible for the abnormal dot deformation) are less and/or the gaps formed have smaller size.

Summary/Conclusions

The root cause and mechanism of the abnormal gravure dot deformation (dots are significantly larger than the corresponding gravure cells) were identified. Based on the literature data, analysis of gravure prints and calculations described in this paper the following observations were made and the following conclusions were drawn:

- Abnormal dot deformation is observed only on paper. No abnormal gravure dot deformation is observed when printing on plastic film (flat surface)
- Free spreading of ink deposited from the gravure cell onto paper surface is limited or non-existent.
- High fidelity gravure dot gain is mostly due to the ink spreading in the grooves formed between the gravure cylinder and paper surface at the entrance and exit from the nip.
- As the paper surface is not flat, a gap can be formed in the printing nip between the paper surface and the land area of the gravure cylinder surrounding the cell.
- During the dwelling time, ink can penetrate into the gap the distance equal to or greater than the size of the small gravure cell (depending on the dimensions of this gap).
- Paper flatness and not the roughness has a critical effect on the gravure print quality.
- The extent of abnormal deformation of the gravure dots depends on paper surface topography (deviations of paper surface from flatness).

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