Color Radiant Fusing with Continuous and Flash Radiation

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Abstract

Radiant fusing in the wavelength range between 500nm - 10μm (visible - far infrared (IR-C)) with continuous radiation or pulsed radiation is used in copying and printing since the early days of commercial application of electrophotographic technology.

The application of radiant fusing to electrophotographic color printing is limited by the lower absorption of radiation of color toner compared with black toner and different absorption of radiation of different colored toner. The commercial application of the radiant fusing technologies for color toner is limited to the wavelength range of 4μm - 10μm. Due to low energy density of the radiation in that wavelength range the process speed is relatively low.

It is desirable to use these technologies for higher speeds as well. It is - among others and compared with hot roller fusing technology - expected to be more reliable, avoids fusing oil and has lower costs.

We have evaluated the use of high intensity continuous and flashed radiation for color independent radiant fusing and have chosen the UV range from 200nm – 380nm (UV-C – UV-A) of the spectrum that combines high intensity and low color dependency.

Our work is explained in detail like matching of emission spectra of lamps with absorption spectra of the toners by toner means and fuser modifications, process and material optimization and finally the potential of the technologies for future toner based high speed color production printers is discussed.

Introduction

Definition

Fusing is the fourth step of the electrophotographic process (Figure 1) consisting of the steps: 1. imaging, 2. inking, 3. toner transfer, 4. fusing, 5. cleaning. We concentrate in this paper on fusing of dry toner often called dry ink as well. Fixing of the toner powder is a process that includes liquefaction, sintering, spreading, penetration into the paper and re-solidification (Figure 2). Most common materials having these characteristics are based on thermoplastic resins.

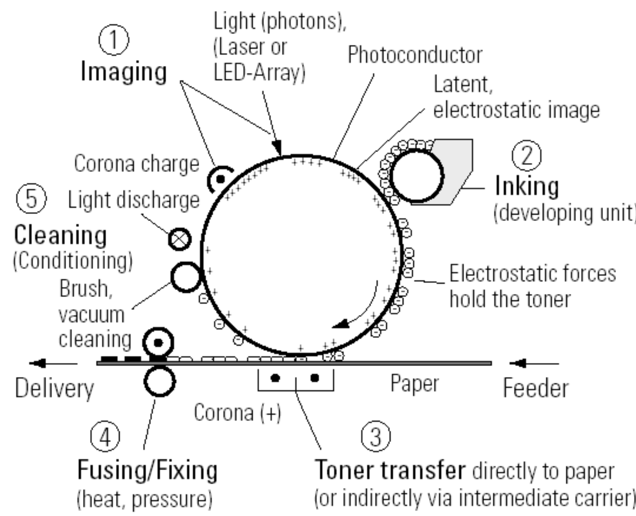

Figure 1. Basic Principle of Electrophotography[1]

Toner is not only fixed to the paper but additionally the surface quality has to match the gloss and other print quality specification. The complete process of fixing and matching the image quality as far as it is fuser related we call fusing.

Other digital printing technologies like electrographic, ionographic or magnetographic printing use toner as well. The teaching of this paper is valid for them analogously if they use color toner.

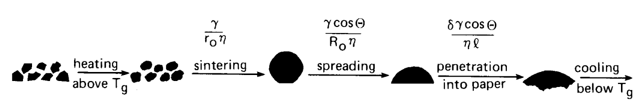

Figure 2. Processes involved in fixing[2]

History

A variety of technologies were used to apply energy to the toner (and the paper) which cause the toner to fuse on the surface of the paper.

In early days of electrophotography and related processes non-contact heating, vapor fusing or cold pressure fixing were used.[3] The non contact heating methods used were mainly flash-, IR- or convection- fusing (see e.g.[4]).

Since more than 20 years the most common fusing technology is hot roller fusing where toned paper passes through a pair of rotating rollers, at least one is heated. The heat melts the toner and the roller pressure pushes it into the paper[5] (Figure 3).

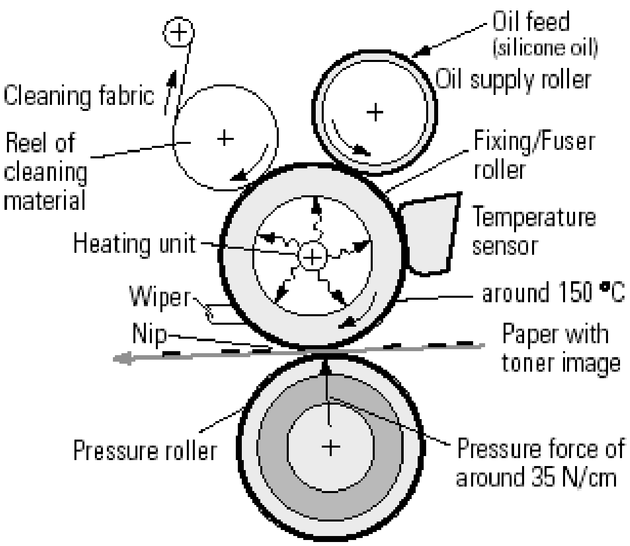

Figure 3. Example of heat roller fusing unit[6]

Nowadays in low and medium speed printing hot roller fuser is the dominant technology.

In principle black and white[7] and process color[8] (mostly 4 color)-fusing technology has to be distinguished. Spot color (two color) printing is assigned to black and white printing as it is done by modified one color printers. Main differences are

	Black and white	Process color
Max. toner layer	100%	400% (290%)
Preferred gloss	Matte	glossy
Paper stock	Small range	Wide range

Widely used in the field of high speed b&w production printers is the use of "hybrid" fusers which are combinations of more than one technology e.g. a contact paper preheater with a roller fuser in high speed web electrophotographic printing above app. 0,75m/s or pressure transfixing combined with flash or radiant fusing used in high speed web iconography.[17]

For industrial color printing machines (digital presses) the demands regarding paper processability are further widened and include paperweight up to app. 300g/m² and a broad variety of substrates including coated and textured papers.

In production printing a variety of non contact fusing technologies are used beside roller fusing like IR- and flash fusing. For dry toner based color printing hot roller fusing is still dominant with a single exception where long wavelength IR-radiation is used.[9]

Motivation

Contact fusers like hot roller fusers have been widely used. However their failure rates and associated maintenance and the use of silicon oil as release agent have driven a search for more reliable technologies, which have less costs over the lifetime of the machine and show better fusing quality as well. Thus we have evaluated the non-contact radiant fusing methods using flash or continuous radiation for their potential as future fusing technologies for color production printing.

Absorption Characteristic of Color Toner and Paper

IR-radiation is used so far for non-contact fusing of toners. For single color (black) printing IR-A and IR-B radiation is used since a long time (Table 1).

Table 1. Characterization of the optical spectrum:

UV-C	100nm – 280nm
UV-B	280nm – 315nm
UV-A	315nm – 380nm
Visible	380nm – 780nm
IR-A	780nm – 1400nm
IR-B	1400nm – 3000nm
IR-C	3000nm – 10^6nm

For color toner so far only IR-C radiation is used where the paper and the toners absorb nearly 100% of the IR radiation.[9] The absorbency of the toners in the three process colors cyan, magenta and yellow on one hand and that of black toner on the other hand differ significantly in the wavelength ranges <5µm (Figure 4, Figure 5).

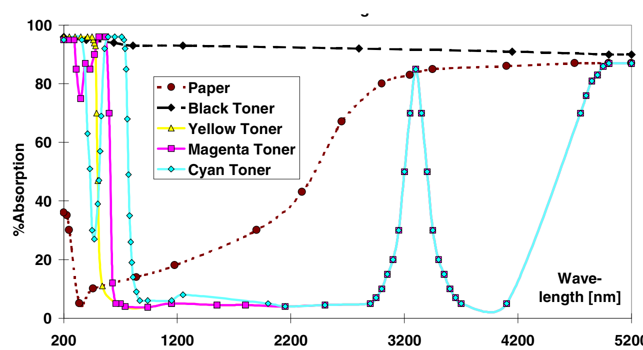

Figure 4. Absorbency of paper and process color toner in the wavelength range from 200 – 6200nm (schematically)

The paper absorbs typically less than 10% in the visible, more than 60% above 2,5µm and nearly 100% IR-radiation above 10µm. The process color pigments absorb in limited wavelength-areas in the visible and absorb typically less than 10% in the IR-range below 2,5µm. Black toner absorbs about 90 - 95% in the mentioned wavelength range between 0,8µm and 10µm.

These different absorption characteristics cause non-uniform fusing behavior, when fused with IR-A and IR-B radiation, which maybe seen as non-uniform fixed toner, non-uniform gloss, partial blistering of toner (so called micro-blistering) or coated paper or partial overheating of the paper with color change.

This effect is most significant between the three process-color toners, which absorb slightly different but all very selectively in the wavelength range between 0,8 and 4,5µm and the black toner, which absorbs about 95% in that wavelength range. Due to this unequal absorption of black toner, color toner and paper non contact IR-fusing of full color prints is so far only possible by using IR-radiation above app. 5µm, where toner and paper absorb basically all IR-radiation.[7] In this wavelength range the energy density of the IR-light is relatively low, so that the time for fusing is long. To realize a long fusing time the size of the fusing area has to be very large or the speed of the printer is limited.

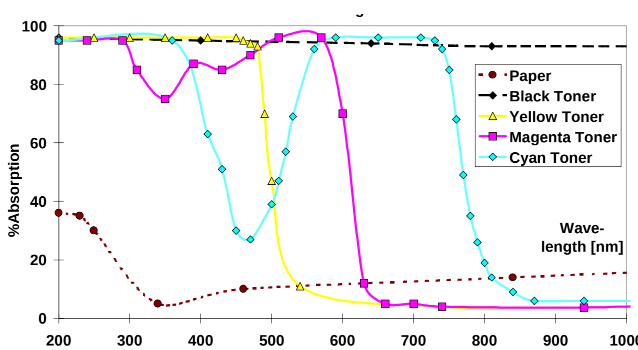

Figure 5. Absorbency of paper and process color toner in the wavelength range from 200 – 1000nm (schematically)

Alternatively IR-absorbers may be added to the process color toners to match the absorbency characteristic of the black toner in the wavelength range between 800nm and 2 µm.[10] These kind of absorbers are so far much too expensive to be used in consumables like toner and are not completely colorless in the visible range so that they may have negative influence on the color reproduction.

Concept Selection

We have concentrated our work on light sources that have a significant part of the emission in the UV-C and UV-B range of the electromagnetic spectrum (200 – 315nm) as these lamps have a relative high intensity and the toners of different colors absorb similar in this range. The absorption of the paper in this range is 15 – 40%. The lamps have emission in the visible range as well which has to be taken into account.

Experimental Setups

For both fusing technologies similar experimental setups were used.

Radiant Fusing Breadboard (Figure 6)

The samples (8) are transported by a linear guide (2) under an UV-lamp (3) and an optional IR pre-heater (7) with an in a wide range adjustable speed and power. The breadboard is designed to absorb the radiation from the lamp during turn-on time and stand-by to avoid heating-up of the breadboard (4,5,6) and to shield operators from UV-light (1).

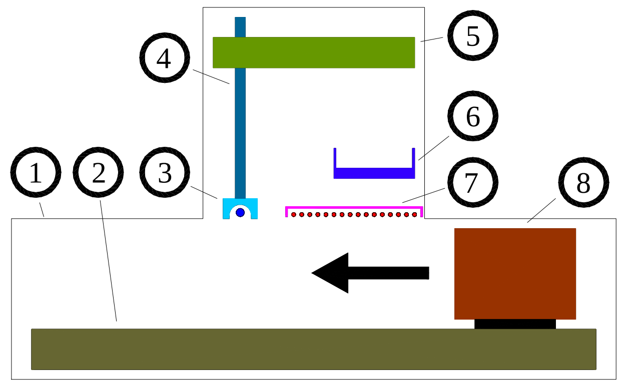

Figure 6. Experimental radiant fuse Flash fusing experimental setups

The experimental flash fuser installed in a similar breadboard consists of a lamp housing (Figure 7) carrying two 2” Xe-quartz bulb lamps (Rapp-Optoelectronics). Optionally Hg is added to boost the UV-portion of the spectrum. The inner diameter of the lamps is 4 mm. The reflector is designed so that two parallel lamps illuminate same area and can be used jointly or delayed. The power supplies of both lamps are equipped with variable capacitors up to 3260µF at a maximum voltage of 450V. An active cooling system was installed to allow continuous running of the breadboard.

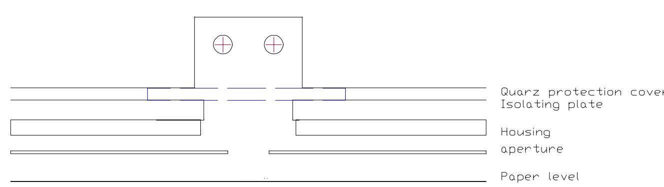

Figure 7. Experimental flash-fuser (sectional drawing of the lamp housing)

Enhancing UV-Fraction

Xe-flash lamps emit a broad wavelength band from UV to IR. Mercury (Hg) was added into lamps to enhance the UV portion.[11] Thus the UV-part of the spectrum could be enhanced from app. 10% to 15%.

For continuous radiant fusing a commercially available HG-vapor lamp with enhanced UV-portion (UV-Technik Meyer GmbH UVH 1540/45 –O) was used.[12]

For the flash lamp most of the intensity is still in the visible range, where the different colors absorb differently. For color independent fusing the visible part has to be cut off by filters.

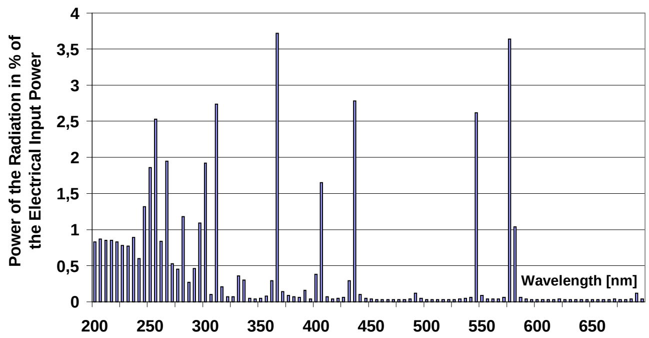

Figure 8. Radiation Power vs. Wavelength for a Continuous High Power Mercury Lamp

Toner

Sharp Melting Toner

Toner for roller fusing has a certain inner cohesion that shows disadvantages when used for radiant fusing. For fusing with hot rollers heat and pressure is used. In a non-contact fusing process the toner has to flow without pressure. That requires a toner with low melt-viscosity. An additional requirement is no tacky behavior in the temperature range below 50°C to avoid problems in development and storage. Therefore a special toner was designed for this work.

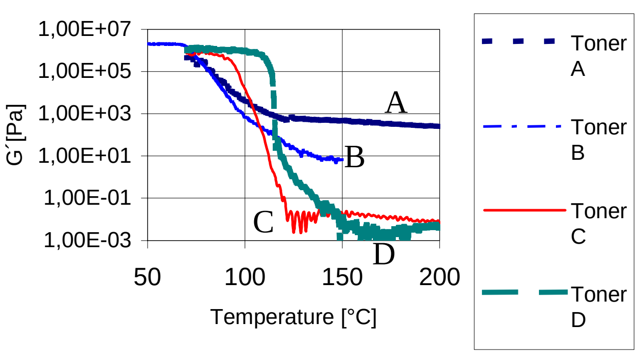

Figure 9. Elasticity of toners designed for roller fusing and for radiant fusing

Figure 9 shows the main difference to a roller fuser toner: The elastic modulus of toners measured with a Bolin rheometer is plotted against the temperature. Two toners from commercially available color printers with roller fusing (toner A and B) show a flat behavior whereas the toners specially designed for radiant fusing shows a sharp decrease of elasticity over orders of magnitude above the glass transition point.

Samples

The sharp melting toners of the different colors were mixed with 30µm hard ferrite carrier and this developer was inserted in a laboratory magnetic brush coater. The coater produced 20mm x 100mm sharp melting toner patches of 10%, 100% and 290% area coverage directly on the paper. For comparison purposes equivalent patches were produced with a commercial toner for roller fusing

Experiments

Flash Fusing

Sharp Melting Toner

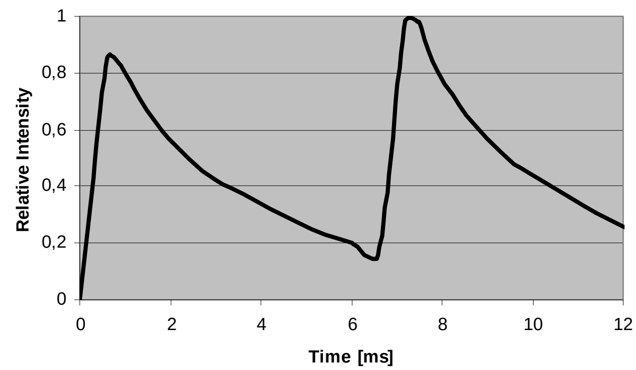

Figure 10. "10ms-double pulse" made by combination of two 2,5ms pulses from two flash lamps illuminating the same area

Flash Fusing of sharp melting toner D and conventional roller fusing toner B were compared using flashes of 2.5 to 10ms pulse length.[13] To avoid reduction of the UV-portion by using single 10ms pulses two pulses of 2.5µm (one from each lamp) were combined without delay to produce a 2.5µm pulse or with delay to produce longer pulses. (Figure 10) shows a double pulse of app. 10ms length produced by a combination of two 2,5ms-pulses.

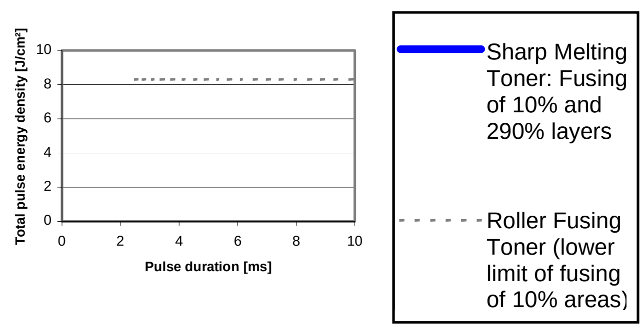

Figure 11. Flash fusing of 10% and 290% contone samples of sharp melting toner in comparison with hot roller fusing toner

Figure 11 shows the results of the cyan toners: The minimum fusing energy necessary to fuse 10% layers differs by factor 2 between both toners. Sharp melting toner shows a fusing window at this pulse energy. Conventional toner shows no fusing window due to unwanted effects (bubbles, color change) on 290% patches.

Discoloring IR-absorbers

Sharp melting toner reduces the energy necessary for flash fusing but does not solve the problem of different absorption of the different colors. As discussed above IR-absorbers can help to use the IR-part of the Xe-spectrum for fusing and to reduce color dependence. Different concentrations of an IR-absorber were added to the toner B. With the specific absorber used here, the color of the toner is darkened due to slight absorption in the visible range of 550 - 780nm. Figure 12 shows the dependence of the lower limit of fusing of 10% layers of a conventional cyan roller fuser toner under flash fusing on the concentration of the IR-absorber added to the toner core formulation. Probably, there is already a strong effect for concentrations below 1%. Thus the flash fusing energy could be matched to that of black toner.

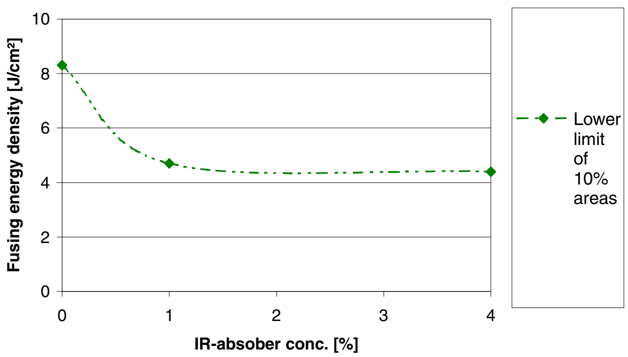

Figure 12. Flash Fusing of 10% contone samples with different concentrations of IR absorber added

The darkening of the color was eliminated by the addition of a discoloring absorber to the toner formulation containing IR-absorber.[14] The irradiation of visible light initiates photopolymerization of the dye with a second component shifting the absorption band from the near IR- to the UV-range. 8% discoloring absorber was added to a toner containing 4% IR-absorber. A 290% cyan patch discolors, when fused with 2J/cm² flash light. The fused layer is slightly yellowish indicating a slight absorption in the low wavelength of the visible range of the spectrum.

Fusing of Toner Containing Neutral Black Pigments

The use of neutral (non carbon-) black pigments reduces the absorption differences between black and the three process colors. The carbon black was exchanged to a mixture of the three process colors cyan, magenta and yellow. When the carbon black was fully exchanged to neutral black pigments the black toner could be fused under similar conditions as the cyan toner.[15]

Duplex Flash Fusing

With flash fusing the fusing energy is incorporated into the paper from the surface. Nevertheless it was necessary to evaluate paper backside temperatures during flash fusing as the backside temperature of the paper should not exceed the glass transition point of the toner to avoid smearing of the toner on the paper transport means.

A fast Pyrometer has been installed at an flat angle to the paper surface to avoid influences of the IR part of the flash lamps transmitted through the paper and the surface temperature of toner or paper was measured as a function of time. The sample papers with 290% sharp melting toner layers were electrostatically tacked onto a Kapton foil simulating a paper transport belt. The flash energy density was increased stepwise up till backside artifacts appeared. The results indicate that backside image artifacts of toners start well above the targeted flash energy density (of app. 3J/cm²).

Radiant Fusing

Radiant fusing was investigated for conventional toner and sharp melting toner on different paper types.

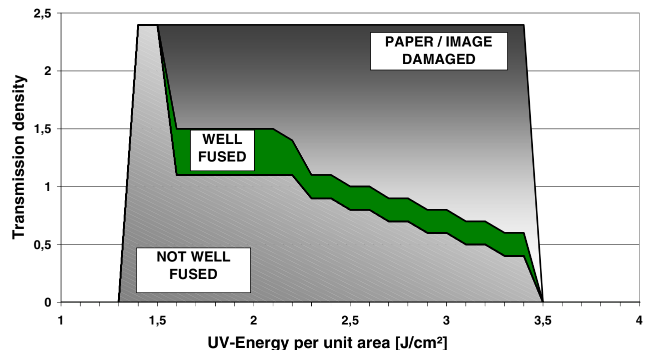

Figure 13.UV- Radiant fusing using conventional toner optimized for roller fusing; glossy coated paper Magnostar 135g/m²

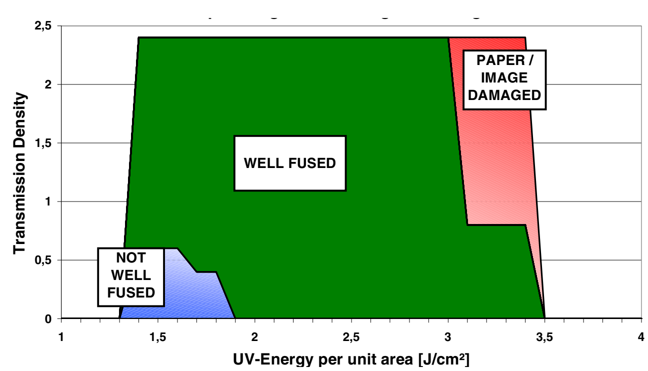

Figure 14. UV- Radiant fusing using sharp melting toner; glossy coated paper Profigloss 135g/m²

The spectrum of the lamp with a UV portion of >60% is sufficient for fusing color independent without additives like discoloring IR-absorbers or neutral black pigments.

As mentioned before the toner and the substrate in the interface area between toner and substrate has to be heated. For a low density toner layer the energy for fusing has to be higher than for a high density toner layer because of the relative low absorption of the paper even in the UV wavelength range. That means that the low-density toner layer determines the fusing window (Figure 15). This effect is even worse for low-density toner layer on heavy weight paper. For lowering the needed energy for low-density toner layers the absorption of the paper has to be increased or in the areas with low-density toner layers clear toner has to be added.

The fusing of coated and uncoated paper shows a fundamental difference for the high-density toner layers. The uncoated paper shows no negative effects until a relative high energy per unit area of 4.2 J/cm². The high-density toner layer on coated paper starts to form visible micro blisters in the toner layer at ~3J/cm² and by further increasing of the energy coated paper starts to blister.

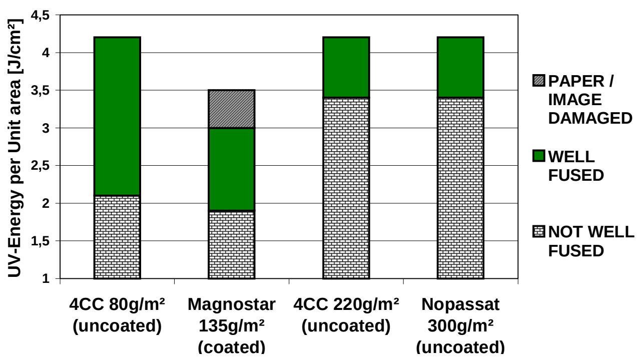

Figure 15. UV-radiant fusing; Fusing window of sharp melting toner on different papers

Duplex Radiant Fusing

Depending on the lamp type, lamp geometry and the process speed the heating time is in the range of 100ms – 400ms. When this technology is used in printers with duplex loop where the paper passes twice the fusing station the first printed image will be heated again above the glass transition point (Tg) during fusing of the second printed image. As a consequence the first printed image could be damaged during fusing of the second printed image by any contact paper transport devices. A possible solution is the use of UV-curing toner[16] or the use of a non-contact paper path device for the fuser and the cooler behind the fuser.

On the uv-radiant fusing is a preferred technology for a single pass duplex web printer, where both sides of the paper maybe fused simultaneously similar as it is already done in the IR-C wavelength range.[9]

Comparison

Comparing flash and radiant fusing there are similarities and differences:

Exposure Timing: Flash fusing covers the exposure range between app. 1ms and 10ms. Above app. 2.5ms a combination of pulses has to be used to avoid reduction of UV-part of the spectrum by prolongation of the single pulse.

Radiant fusing leads to exposure timing >100ms depending on lamp technology and speed. The short exposure time from the surface achieved with flash fusing leads to low paper temperatures and reduced duplex fusing problems in the case of two pass duplex printing.

UV-portion: Continuous Hg-vapor lamps have UV portions above 60% and allow color independent fusing.

At flash fusing UV-portion could be enhanced from 10% to 15% only by the addition of Hg. Here further progress is necessary when the use of filter technology with low yield shall be avoided. Alternatively substantial toner modifications like discoloring IR-absorbers and/or neutral black pigments are necessary for compensation.

Conclusion

We have evaluated the potential of the non-contact fusing methods “UV-Flash-Fusing” and “UV-Continuous Radiant Fusing” for their potential as fusing technology for color for production printing application. We have found that there is a potential if a special new developed sharp melting toner is used. For flash fusing the UV-portion of lamps has to be significantly enhanced or discoloring absorber and/or neutral black pigments have to be used.

Further work and progress is necessary before one of these technologies can be used for fusing in toner based color production printing whereas UV–radiant fusing is specially useful for single pass duplex printing.

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Biography

Domingo Rohde received his diploma in physics in 1994 and joined Heidelberg Printing Machines in 1997 and later NexPress in Kiel, Germany. Since this time he worked for the Advanced Technology department dealing with non-impact printing technologies. Currently he is the chief engineer of the Advanced Technology department of NexPress in Kiel.

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