Thermostar : A new Thermal Litho Printing Plate Technology for CTP Recording

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Abstract : In this paper the most recent evolutions in litho printing plate technology for computer-to-plate imaging are briefly discussed with emphasis on the recent market interest in thermal plate technology. A new thermal plate technology, called Thermostar, is introduced and discussed (plate construction, basic working principles). Subsequently, the performance of this plate is analyzed in detail (sensitivity, image quality, run length capability etc.). The paper concludes with some considerations about the future of litho (plate) technology.

Overview of the present CTP landscape

When we look at the present computer-to-plate landscape, we are confronted with a vast variety of plate technologies and imaging hardware concepts. Not surprisingly, for an emerging new application area that requires new innovative technology and lacks standardization, quite a number of companies have developed their own ideas into product and system offerings. The result is the heterogeneous picture we see today, comprising plate and platesetter products with quite different characteristics and requirements and with a number of incompatibilities amongst them.

Let us take a closer look at the present digital litho printing plates. They come in all kinds of "colours and flavours". Silver halide diffusion transfer, photo-polymer and so-called hybrid plates are sensitive to visible laser light, ranging from blue to red. We can also call them 'photo-mode' plate systems, because

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the actinic radiation from the laser induces a direct photonic response in the active or sensitive layer that gives rise to a latent image, leading – after one or more development steps – to the final image carrying press-ready plate. Today they are all called 'high sensitivity' or ' high speed' plates, still their absolute sensitivity values span a range of 1 to 250 approximately, with silver halide plates requiring the lowest energy level (see Figure 1).

Agfa offers 3 types of aluminum based digital printing plates to the market today : (i) Ozasol N90A, a negative-working photopolymer type of plate being green and especially blue sensitive; (ii) LithostarPlus, a positive-working silver halide diffusion transfer type of plate (Remmerie, 1993) coming in 3 versions : LithostarPlus LAP-B (blue sensitive), LAP-O (orthochromatic or green sensitive) and LAP-R (red sensitive) (Van hunsel et.al., 1997), and (iii) Silverlith SDB, a positive-working green and especially blue sensitive silver halide diffusion transfer type of plate (recently acquired from Dupont-Howson). Agfa also offers a polyester based digital printing plate to the market today : Setprint, which is also a positive-working silver halide diffusion transfer reversal type of printing plate coming in 2 versions : Setprint SET-HN-LL (red sensitive) and SET-IR-LL (infrared sensitive).

The third category of visible light sensitive plates uses so-called hybrid silver halide technology. This type of plates has a photographic emulsion applied on top of a conventional type of UV-sensitive plate. This emulsion is exposed imagewise, developed and acts subsequently as a light mask for the underlying UV-sensitive layer (during a UV flood exposure). The CTX plate assortment (both positive and negative-working, blue, green and red sensitive versions) of Kodak-Polychrome Graphics (KPG) is the only commercially available example of this plate technology today.

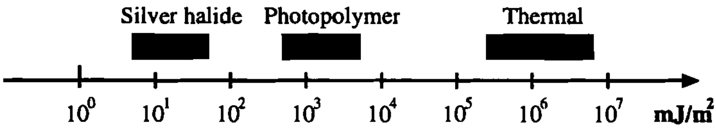


Figure 1 : Schematic overview of typical digital litho plate technology sensitivity values

In addition to the above mentioned visible light sensitive or 'photo-mode' plates, we currently witness the introduction to the market of a new family of digital litho plates that catches a lot of attention : the so-called thermal plates. Thermal plates are characterized by their sensitivity to an (imagewise) applied rise of temperature, which is induced by infrared laser radiation. We can also call them 'heat-mode' plate systems, because the actinic radiation from the laser induces a rise of temperature in the active layer that gives rise to a latent image, leading – after one or more development steps – to the final image carrying press-ready plate.

Thermal plates are in general sensitive to radiation in the range of 830 nm up to 1064 nm or even higher, with absolute sensitivities that are about 50,000 to 500,000 times lower than what is known for silver based digital litho plates (see Figure 1).

Different thermal plate technologies have been described in the literature. Some thermal plates are based on polymer crosslinking technology, other plates are based on ablation or ablation transfer, and still other plates have physical insolubilisation as their working principle. Some need wet processing, other are (almost) processless. Some are conventional (wet) litho plates, others are waterless litho plates. If we limit ourselves now to thermal wet litho plate technologies that still make use on-press of the highly hydrophilic properties of electrochemically grained and anodized aluminum in the non-image parts, we can consider four technologies.

One thermal plate technology is based upon thermally induced chemical insolubilisation of the active layer by polymer crosslinking. This negative-working plate technology requires a preheat step (oven) after imaging, followed by a conventional wet processing step and an optional post-bake step for achieving higher run lengths. The preheat temperature tolerances are quite narrow, meaning that a tightly controlled preheat oven is required. The best known commercially available representatives of this plate technology are the Kodak-Polychrome Graphics (KPG) DITP and Quantum 830 plates (Walls, 1994; DeBoer, 1995). A limitation of this technology is its unsuitability for internal drum imaging, which presently requires plate sensitivity in the range of 1050 nm-1150 nm, compatibility with short pixel dwell times in the range of 10-100 ns, and very high image plane power density values. Furthermore, this plate technology is not completely daylight-safe (yellow room light conditions required).

Another technology is based upon thermally induced chemical solubilisation of the active layer. This positive-working plate technology does not require a preheat step and can be fully daylight-safe. It only requires a conventional wet processing step and an optional post-bake step when higher run lengths are required. The best known representative of this thermal litho plate technology is the Horsell (Kodak-Polychrome Graphics (KPG)) Electra DC plate, which is not commercially available yet. This plate however does not allow for internal drum imaging (only sensitized for 830 nm).

A third technology is based upon thermally induced physical insolubilisation (fusion) of the active layer, containing a well-chosen dispersion of polymer latex particles. This negative-working plate technology may require a post-bake step after the conventional wet processing step. A representative of this thermal litho plate technology is the Agfa RD9 plate (recently acquired from Dupont-Howson), having a broadband sensitivity in the range 830 nm-1100 nm and being compatible with both external and internal drum recording technologies. Agfa RD-9 is not commercially available yet.

A fourth technology is similar to what we have called hybrid silver halide plate technology before (visible light sensitive plates). Upon imagewise exposure to IR radiation the top layer becomes insoluble in a conventional alkaline developer and acts subsequently as a light mask for the underlying UV-sensitive layer (during a UV flood exposure). As far as we know, only Kodak-Polychrome Graphics (KPG) will offer this plate technology (under the name Quantum NPH) to the market.

Finally, there is a fifth thermal plate technology that has been developed by Agfa and is uniquely available from Agfa : the Thermostar technology, which is a very convenient plate technology. This positive-working plate technology is the subject of this paper and will be explained in more detail. It will become clear that this plate technology has the following performance characteristics to meet the thermal plate expectations in the market :

-it is completely daylight-safe,
-it does not require a preheat step and only needs a conventional wet processing step with a commercially available conventional positive plate developer,
-its press-behaviour is that of a conventional litho plate,
-post-baking is optional if very high run lengths are required,
-it is compatible with all existing thermal platesetter architectures (internal drum as well as external drum) and laser wavelengths in the range of 830 nm up to 1150 nm or higher,
-its imaging and processing performance is consistent, independent of plate age and ambient conditions,
-it has very convenient storage requirements and shelf life expectations,
-its latent image stability is almost unlimited.

Thermostar thermal litho plate technology

Thermostar plate construction.

The Thermostar plate consists of 2 layers on top of an electrochemically grained and anodized aluminum substrate (see Figure 2). These 2 layers are coated in one single pass through the coating alley. This coating technology is very similar to the technology used for conventional contact sensitive plates and high-speed photopolymer plates and enables us to optimize the performance of a plate because it allows to bring in specific functionalities in separate layers.

The aluminum substrate used is identical to this used for several plates in the Agfa Ozasol conventional plate assortment. It is a state-of-the-art electro-chemically grained, anodized and post-treated substrate, used for many years now and known for its excellent lithographic performance.

The first layer on top of the aluminum substrate (thickness about 1.1 µm) consists of a state-of-the-art Novolak type of hydrophobic polymer and has been optimized in order to achieve (i) a good lithographic behaviour in terms of run length capability with and without baking and (ii) an optimum developability and clean-out performance with a standard aqueous alkaline developer for conventional positive plates (Ozasol EP26). This optimum clean-out performance guarantees a very good ink/water balance, resulting in a low dot gain. This layer is insensitive to light of whatever wavelength (desensitized).

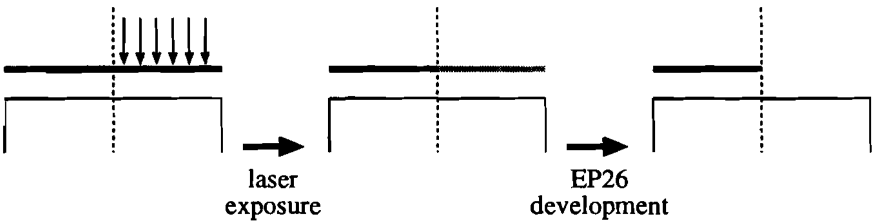


Figure 2 : Thermostar plate construction and working principle.

The top layer is a submicron thick infrared sensitive, highly hydrophobic layer with optimum ink-accepting performance and insoluble in the aqueous, alkaline developer used. As such it forms a physical barrier for development of the first layer. This top layer can be carbon sensitized (broad-band IR-sensitivity) or dye sensitized (narrow-band IR sensitivity, e.g. 830-870 nm or 1050-1150 nm). Furthermore, this top layer may contain a contrast dye, especially when the layer is not carbon sensitized. This dye has no other function than to give the press-ready plate the necessary contrast. It does not interfere in any way with the Thermostar technology working principle.

Both layers have been optimized in order to have identical lithographic properties, so that plate performance is guaranteed to remain constant over longer press runs.

Due to this simple plate construction and the fact that both coated layers are very simple from a formulation point of view, the Thermostar plate manufacturing and coating proces can be controlled very well. As a result the plate batch-to-batch sensitivity and performance differences are very small. E.g. the maximum plate batch sensitivity variation today is less than ± 0.05 logH.

Thermostar technology working principle

The working principle of Thermostar technology is the thermally induced structure deformation of the physical mask top layer (see Figure 1). Upon absorption of IR light by carbon or IR dyes in the Thermostar plate top layer, the infrared light is transferred into heat. It has been observed that the temperature in this kind of thin, active layers can increase very rapidly upon exposure to a high power focussed laser beam and this to temperatures as high as 400 °C or more (Hare et.al., 1997a and 1997b). The exact temperature depends on the thermal diffusion coefficient of this active layer, the time-scale of exposure (pixel dwell time), and furthermore the thickness of the active layer and the thermal diffusion coefficients of the adjacent layer(s). It is known also that this kind of thin, active layers may undergo some form of expansion as a result of such a laser pulse, resulting in a higher layer volume/thickness (Bennet et.al., 1996). This layer decompression may result in a layer structure, which is completely different from the original coated layer structure. It is also known that still higher energy levels in the same time scale of exposure may finally lead to layer ablation (partial or total layer destruction upon the generation of volatile compounds that blow off the layer more or less violently) (Bennet et.al., 1996).

Because of the high IR light absorption capacity of the thin top layer of the Thermostar plate, a high temperature can be induced in this layer at a relatively low exposure level (e.g. 25 mJ/cm^2 at a 0.03 μs pixel dwell time). As a result a physical deformation of the top layer takes place.

This physical deformation of the top layer structure not only allows the aqeous alkaline developer to wet the exposed parts of the plate more efficiently, but also enables a faster penetration of the developer through this top layer, under which the underlying layer can be dissolved much more effectively and faster than in the non-exposed areas. As such the top layer acts as a kind of physical mask for the alkaline developer and it will become immediately clear now that the (dynamic) surface and interfacial tension (developer/top layer interface) is an important process parameter.

The change in wetting and penetration behaviour of the top layer upon IR laser exposure is illustrated in Figure 3.

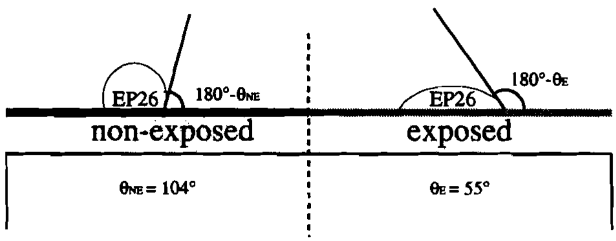


Figure 3 : Ozasol EP26 developer contact angle on laser exposed and non-exposed parts of a Thermostar plate (60 s. after drop formation).

We can conclude that the Thermostar technology can be described as the imagewise creation of a physical developer action differentiation. This unique non-ablative process enables imaging without the formation of unwanted volatile compounds and dust consisting of (partially) degenerated layer components. When such components get into the working area atmosphere, they may give rise to environmental as well as health risk concerns. Even when they do not get outside the platesetter interior, they might cause considerable problems by affecting the efficiency of specific optical parts. Non-ablative plate technology makes special dust suction devices close to the imaging area completely redundant, devices that may be required for ablative technologies.

Processing of Thermostar plates is carried out in a conventional processor at approximately 1.0 m/min, using the standard Ozasol positive plate developer EP26 (at 25 °C) and using conventional regeneration (Ozasol EP36) and gumming chemistry (Ozasol RC795). It is also possible to regenerate with fresh developer (so-called 'top-up' regeneration).

Demonstration of the non-ablative nature of the Thermostar imaging technology.

Ablation may comprise decomposition and vapourisation of (a part of) the IR-sensitive layer, during which the physical and chemical nature of (this part of) the layer is changed. When this active layer is also the top layer, the ablated material is vapourized into the air and in most cases partly redeposited as a solid (powder) on the surface of the material, where it can possibly interfere with the further imaging of the material, especially when the degree of ablation is important. This solid powder can be removed by simple rubbing resulting in a thinner final layer and a lower optical density when the layer is evenly coloured throughout its thickness. For ablative technology media this can be monitored visually and measured.

In order to prove the non-ablative nature of the Thermostar imaging technology the following experiment was performed. A Thermostar dye sensitized plate version was exposed on a Creo TrendSetter 3244 (2400 dpi) external drum platesetter. The resolution exposure setting (the 2x2 up to 8x8 checkerboard patterns matched visually (same density)) was about 180 mJ/cm^2. After exposure, the optical density was measured in the exposed as well as in the non-exposed areas (the results are given in Figure 4). The optical density was identical in both areas, indicating that no ablation of the layer had taken place.

Furthermore, when both the exposed and unexposed areas of both plate versions were rubbed off with a cotton pad up to a point at which the exposed areas were damaged (under high pressure), the exposed areas turned out to be damaged to exactly the same degree as the non-exposed areas (see Figure 4). This indicates that no redeposited solids (easy to be rubbed off) had been formed on the plate surface during exposure and that even the mechanical properties of the plate surface layer had not been affected upon exposure.

Finally, chemical trace analysis (FTIR, GCMS, ESCA) of the plate surface (prior to rubbing) showed no differences between exposed and non-exposed areas either, indicating that no redeposition or other chemical changes had taken place at the plate's surface upon exposure.

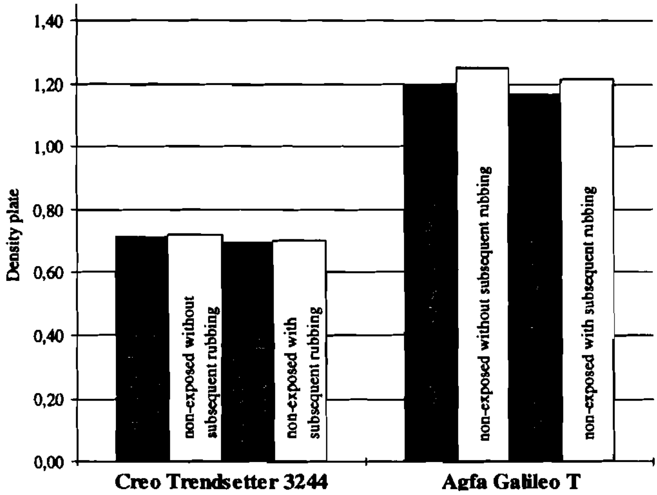


Figure 4 : Optical density (Gretag D186) of the exposed and non-exposed parts of two dye-sensitized Thermostar plate versions upon Creo TrendSetter 3244 and Agfa Galileo T exposure respectively.

The same experiment was repeated with another dye-sensitized Thermostar plate version upon exposure on an Agfa Galileo T platesetter. The resolution exposure at 2400 dpi/16000 rpm (404 m/s) was about 28 mJ/cm^2. Again, we find no indication of any ablation phenomena taking place (the results are given in Figure 4). The slight difference in density upon exposure is due to a slight colour change of the top layer.

Thermostar sensitivity

As indicated before, Thermostar can be spectrally sensitized for 830-870 nm (laser diodes) as well as for 1050-1150 nm (solid state IR-lasers (a.o. Nd-YAG (1064 nm) or Nd-YLF (1053 nm) and even for the newly developed fiber laser technology from Polaroid (1100 nm)). Furthermore, Thermostar is completely daylight insensitive (insensitive to both visible and UV-light).

The absolute sensitivity is dependent on the imaging speed or pixel dwell-time. Thermostar plates, like all other known heat-mode systems, show so-called sensitivity irreciprocity : the sensitivity depends upon the scan speed.

External drum exposure architectures (Gelbart, 1994), like e.g. used on the Creo TrendSetter 3244 and the Scitex Lotem 830 platesetter, use intrinsically slower drum speeds (e.g. Creo TrendSetter 3244 : max. 150 rpm) and in order to achieve a sufficient plate productivity, these architectures need multiple beam technology (e.g. Creo TrendSetter 3244 : 240 beams; Scitex Lotem 830 : 16 beams)). Consequently the pixel dwell time is relatively long (Creo TrendSetter (2400 dpi) : approximately 5 μs at 150 rpm). As a result of this longer pixel dwell time heat dissipates into the adjacent layers and less energy is available for the latent image creating process.

Internal drum exposure architectures (Goulet, 1996), like e.g. used on the Agfa Galileo T and the Gerber Crescent C42/T platesetters, use a single scanning beam and relatively high scan speeds / short pixel dwell times (e.g. Gerber Crescent C42/T (2400 dpi) : 367 m/s scan speed / 32 ns pixel dwelltime (at 12000 rpm)). In this case the available energy is used more efficiently for the latent image creating process.

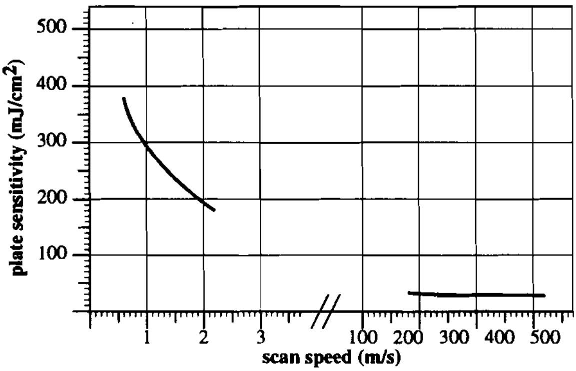


Figure 5 : Thermostar sensitivity irreciprocity curve.

Thermostar plate imaging on internal drum architectures requires about 30 mJ/cm^2 (resolution exposure) and in this speed range the sensitivity is almost independent of scan speed (see Figure 5). However, in the low speed range the plate sensitivity is very dependent upon scan speed. E.g. on the Creo TrendSetter 3244 (2400 dpi) the Thermostar plate requires about 180 mJ/cm^2 at 150 rpm (2.2 m/s) (resolution exposure) and about 300 mJ/cm^2 at 60 rpm (0.9 m/s) (resolution exposure) (see Figure 5). The energy required for imaging Thermostar technology plates on internal drum platesetters is lower than that required for most announced plates; on external drum platesetters it is comparable to what is known for most commercially available or announced plates. As far as our knowledge goes, Thermostar plates are compatible with all currently available or announced thermal platesetters.

All of these observations are not intended to position the available thermal recording architectures (external drum - internal drum), which clearly have their benefits and limitations. They merely serve to demonstrate the broad application possibilities of the Thermostar plate technology.

Thermostar performance characteristics

(1)Plate resolution and image quality characteristics

Like other thermal plate systems the Thermostar plates have a very high resolution. However the actual image quality depends also on the platesetter used. Typically, Thermostar exhibits perfect linear reproduction characteristics over the complete tone range, even for FM-screening technologies using microdots consisting of only 2x2 pixels at 2400 dpi (21 µm) (see Figure 6). The typical tone range rendered on the plate at 200 lpi exceeds 2%-98%. This resolution is far better than required for most applications.

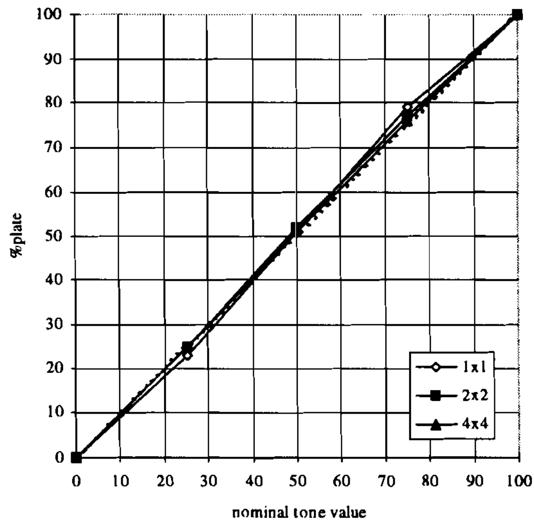
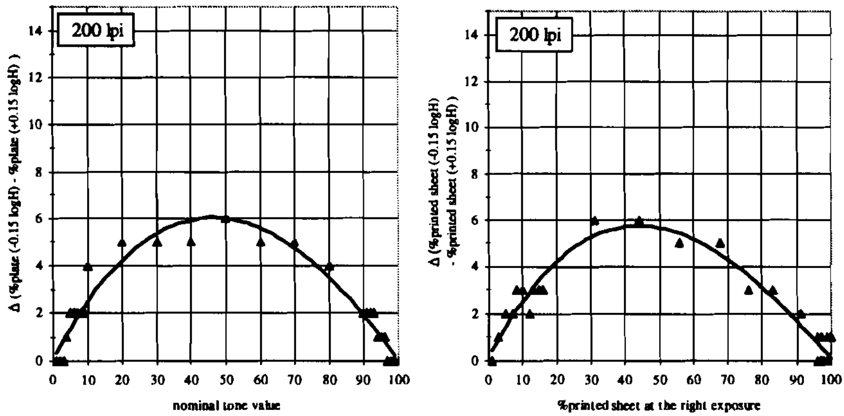


Figure 6 : Plate tone rendering curves (carbon sensitized Thermostar on Creo TrendSetter 3244 (2400 dpi)) for Bayer patterns (Bayer, 1973) with microdots consisting of (1x)1, 2x2 and 4x4 pixels.

(2)Exposure and processing latitude

Figures 7,8 and 9 indicate that Thermostar plates are characterized by a very wide exposure and processing latitude, which will guarantee a high consistency of a Thermostar platemaking system in a customer's working environment.

Similarly as for the reproduction quality of the press-ready plate, the exposure latitude is largely determined by the platesetter used. But also the processing latitude depends upon the optical quality performance of the platesetter used. This is because no wet processing thermal plate technology todays allows for a completely binary imaging process. Procesless thermal plate technologies may possibly offer a route to achieving this.



Figuur 7 + 8 : Exposure latitude of dye sensitized Thermostar plates (exposure on Creo TrendSetter 3244 (2400 dpi)).

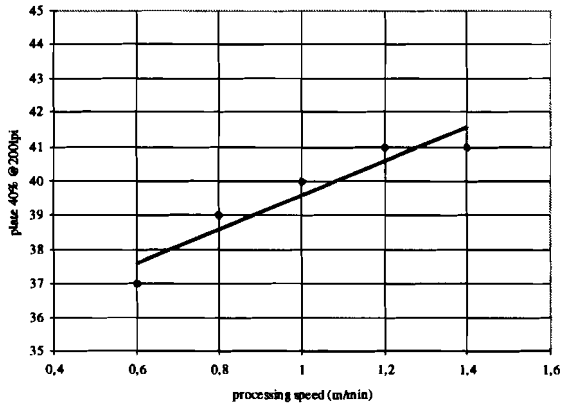


Figure 9 : Processing latitude of dye sensitized Thermostar plates (exposure on Creo TrendSetter 3244 (2400 dpi)).

(3)Lithographic latitude, press gain and run length capability

The lithographic latitude of Thermostar plates has proven to be excellent and this is no surprise since a state-of-the art aluminum substrate is used and a very good clean-out of the non-image parts is obtained upon laser exposure and subsequent conventional development. At the same time both Thermostar layers that are coated on top of the substrate have been optimized to be highly hydrophobic as to achieve a good ink-water balance on the press. As a result we have witnessed dot gain values on the press that are completely in agreement with what is to be expected for conventional positive plates (see Figure10).

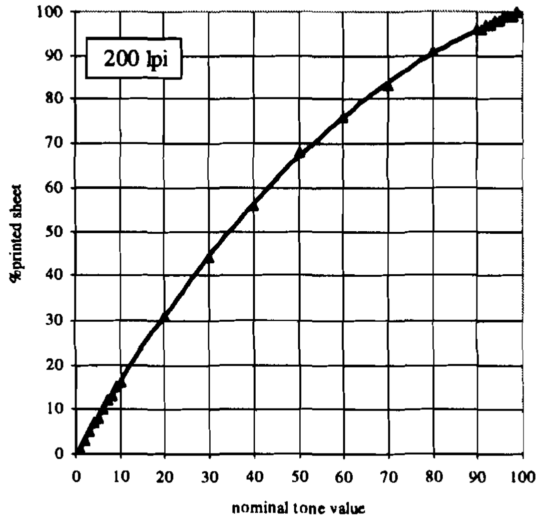


Figure 10 : Thermostar tone rendering curve (printed sheet) (plate exposed on a Creo TrendSetter 3244 (2400 dpi)).

Run length testing under varying conditions (using various types of inks (low tack / high tack), fountain solutions (containing IPA or IPA-replacing agents), blankets (compressible / non-compressible) and paper) was performed and indicated a run length capability higher than 150,000 impressions in all cases. This run length performance is identical to what is to be expected for conventional positive plates. After baking, very high press runs are possible, exceeding 1 million impressions, as is the case for conventional positive plates.

The future of digital litho (plate) technology

The prepress and printing industry is going through a revolutionary transition. One that remodels the whole business by imposing a totally digital workflow. Computer-to-plate is certainly one of the major elements in this transition.

Looking at the broad palette of computer-to-plate offerings that represent a growing number of different digital plate technologies, one has to wonder what the future perspective for these different technologies will be.

Surely, thermal plate technologies seem to have the outlook for a bright future. The figures vary, but most market reseachers agree that in a few years from now, thermal will have captured a quite substantial share of the digital plate market.

Indeed, thermal plate technologies offer some important benefits :
-they are truly daylight safe (but some are not!),
-they offer a very high resolving power,
-their run length capabilities are very high in general.
Also, even though today's thermal plates still need wet processing (at least those that use the hydrophylic properties of electrochemically grained and anodized aluminum), there is the expectation of truly processless thermal plates for the (near) future.
In this respect, high hopes exist for new developments like the Agfa Silverlith SDT plate that can be put on the press immediately after exposure without any wet chemistry development step. This technology seems to allow a real binary imaging process.

From a side perspective, (processless) thermal plate technologies also enable on-press platemaking or even 'plateless' on-press litho technologies (Gelbart, 1996) and in that way they can be considered as catalysts for the development of digital litho printing press technologies.

Agfa believes that in the years to come, thermal will be the logical choice for a number of applications. On the other hand, it must be emphasized that thermal plate technologies exhibit some less favourable characteristics too :
-a lot of energy is needed for their exposure,
-these technologies operate at the limits of today's IR laser technology,
-their energy requirements have implications on laser life and stability and because of that also on the reliability of the whole platemaking system,
-they are relatively new and not completely mature yet, and should therefore be considered pioneering technologies.
Therefore and also because of the high cost today of the required IR lasers, they are probably not suitable for all applications. Not today and not even in the near future. What really matters to a digital plate user is not the nature of the plate itself. What matters is not whether a plate is based on photo-mode or heat-mode technology. What matters is that his plate system offers image quality, lithographic quality and maybe even more importantly consistency, reliability, predictability, convenience and - increasingly more important - environmental safety.

Several of these requirements are very adequately met by today's visible light digital plate technologies. They are proven technologies, that offer the quality needed for various applications and this at a reasonable cost.
Agfa is convinced that also visible light sensitive digital plates have a future. For those environments that require very high throughput e.g. (like newspaper companies) or those users that can only bear a low to moderate system (hardware) cost (in a lot of 'low end' applications), visible light sensitive plate technologies offer attractive solutions and they will continue to do so.

Still, even though the present strong expectations about thermal plate technology may later prove to be somewhat unrealistic, Agfa believes that thermal technology holds a strong promise for the future, and we are convinced to make a significant contribution to litho plate technology progress with Thermostar.

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References

Bayer, B.E.
1973 "An optimum method for two-level rendition of continuous-tone pictures", Proceedings IEEE International Conference on Communications, Conference Record, pp. 26/11-26/15

Bennet, L.S., Lippert, T., Furutani, H.,Fukumura, H. and Masuhara, H.
1996 "Laser induced microexplosions of a photosensitive polymer", Appl.Phys. A63, 327-332

DeBoer, C.
1995 "Graphic Arts applications of laser thermal printing", TAGA 1995 Proceedings, pp. 29-43

Goulet, R.G.
1996 "Drum technology : the influence of imaging surface geometry on image quality", TAGA 1996 Proceedings, pp. 1-13

Gelbart, D.
1994a "High power multi-channel writing heads", Proceedings IS&T's 10th International Congress on Advances in Non-Impact Printing Technologies, pp. 337-339

Gelbart, D.
1996b "On-press imaging for offset printing", TAGA 1996 Proceedings, pp. 613-622

Hare, D.E., Dlott, D.D.,D'Amato, R.J. and Lewis, T.E.
1997a "Pulse duration dependance for laser photothermal imaging media", Proceedings IS&T's 50th Annual Conference. pp. 290-295

Hare, D.E., Rhea, S.T., Dlott, D.D., D'Amato, R.J. and Lewis, T.E.
1997b "Fundamental mechanisms of lithographic printing plate imaging by near-infrared lasers". J.Imag.Sci.Tech. 41(3), 291-300

Remmerie, H.
1993 "Lithostar : A growth path from analog to digital platemaking", Proceedings IS&T's third Technical Symposium on Prepress, Proofing and Printing

Van hunsel, J., Coppens P., Van den Bergh D and Vander Aa J.
1997 "LithostarPlus LAP-R : a new red-sensitive silver DTR plate system for CTP imaging", Proceedings IS&T's 50th Annual Conference, pp. 251-256

Walls, J.E.
1994 "Unconventional printing plate exposed by IR (830nm) laser diodes", TAGA 1994 Proceedings, pp. 259-267