Toner Printing for Secure Documents

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Abstract

This paper presents some specific challenges and opportunities in the security printing sector. As a demonstration of this it uses the example of high security national identity documents. It examines some of the technical problems that are specific to this market sector and the opportunities that arise from these, particularly in the area of the physics and chemistry of the materials in the digital printing process. The work concentrates on electrophotographic (toner) printing. It is noted that mainstream applications are evolving in a direction that appears to be divergent to security print. Finally, the challenge electrophotography faces in this market sector from inkjet is covered, particularly from pagewide printing.

Security printing for high security documents

Security printing is in itself a broad applications space. It has the general aim of deterring forgery and counterfeiting of documents and goods. The level of this deterrence depends on the technologies deployed and is in turn determined by the perceived need. At the top end of these needs come national identity documents for border protection such as passports and entry visas.[1] This is a rather specific application with challenges that may well be unique in the digital printing space. As a result the technical requirements differ somewhat from mainstream applications and are evolving in different directions. A number of these challenges can be considered as counter intuitive to those more used to mainstream applications.[2] These are outlined below.

- Workflow. This is not cloud printing and often not a network printing application. Because of the physical security of the "substrate" (for example blank entry visas) and the personalization data both data entry and printing are usually done within operator reach of each other, or in a closed secure environment.
- Longevity. Identity documents are intended to have a lifetime measured in months or even years. This is rather different to office print where useful lifetimes may be measured in days or even hours.[3,4]
- Deinking.[5] While office and commercial print documents must be made to cleanly release the print in a recycling process a somewhat different driver exists in secure document printing. The printed document must be resistant to the removal of the colorant as this would compromise both the identity of the bearer and border security.
- Substrates. Secure documents in general use substrates many in the printing world would class as challenging. They are pre-printed with a security design so the digital print often has to adhere to both print and paper. Some of the print processes and inks used can calendar the paper surface, making the absorption of liquid inks and the adhesion of toners more difficult. A good example of this commonly used in high security documents is intaglio printing.[6] In addition items such as visas are commonly produced as thick multilayer assemblies with a pressure sensitive adhesive and a peelable backing, a somewhat similar assembly to pressure sensitive adhesive labels. As a result the curl characteristics of these products can be complex and challenging due to the unusual moisture transport.[7]

Good design stipulates that security printing systems are designed as an ecosystem with a print feature hierarchy designed with the above concepts in mind.[2] In the case of the systems used to illustrate this paper a Lean Six Sigma philosophy was followed, utilizing design of experiments techniques to optimize the key input variables in line with critical to quality parameters, in a manner similar to other groups.[8] This was particularly useful in this case as it became evident through this work that desktop electrophotographic printing is evolving in a direction that makes it more difficult to deploy in Security Printing. This is covered in more detail in a later section.

Digital printing for secure identity documents

Secure identity documents such as passports and visas are manufactured to incorporate features to deter forgery and counterfeiting. As a part of this process various impact printing technologies are used. However, these documents then have to be "personalized". This entails the addition of the data that is specific to the individual holder of the document. This may include alphanumeric text (name, dates, etc.) and images such as portraits. It is now almost universally the case that these are applied using various digital printing techniques.

In common with much of the rest of the digital printing space there is an increasing tendency towards full color printing. However, this is by no means universal and monochrome printing still holds a significant position in this field, particularly in with applications with a lower perceived need for print security.

Digital printing using inkjet, thermal transfer and electrophotographic techniques are established in this market. The choice of the individual techniques is usually a result of history, prejudice and (hopefully) some system design. This paper concentrates on the use of electrophotographic techniques in visa printing where the selection can be attributed to the traditional speed advantages these systems have over inkjet systems and the fact that the prints do not emerge wet from the printer. It is also salient to note that this is predominantly an office printing application where IT departments used to interfacing electrophotographic printers are a significant element in the purchasing decision process.

One significant issue in this market is the highly seasonal nature of some of the work. At some times of a year documents are printed in small quantities whist at other times the printers are running almost continuously. As a result the durability of the toner during extended printing can become a particular issue.[9] The electrophotographic system should be selected with this in mind.

Quality attributes for secure print

The quality attributes used to judge secure identity document printing are also rather different to those used in mainstream applications. Objective measures of print quality exist for the graphic arts market and are incorporated in International Standards such as ISO 13660.[10] However, these usually important metrics are secondary to the security of the print – digital “print quality” as we understand it is usually judged by eye as “fit for purpose”. The primary criterion is the security of the personalization print – how easily can it be removed or altered. This market has a different set of Critical To Customer responses.[11]

The main issue in the use of electrophotography on these documents is that with uninformed system choices they can be comparatively easy to remove. In this case the document is compromised and the security of the print is broken. There are high technology routes to toner removal.[12] However on these types of substrate removal can be much easier, as illustrated in Figure 1. In this case the toner from a small element of a printed letter has been cleanly removed with a finger nail.

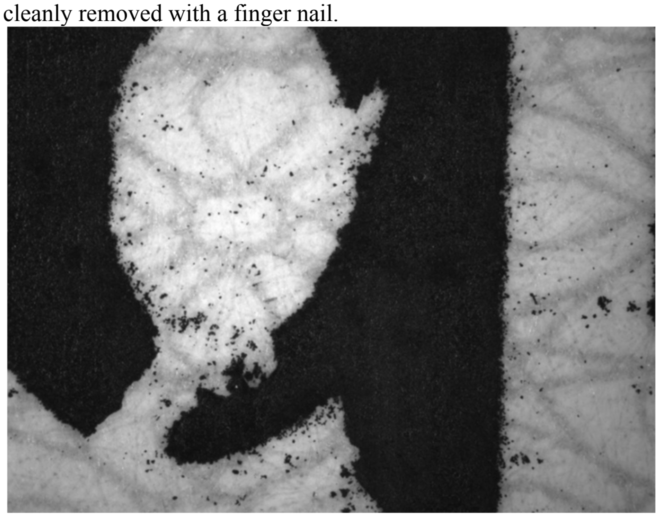

Figure 1 A printed letter "q" where a small area of toner has been removed

Finger nail scratch is a test method sometimes employed by customers in this market as a measure of toner adhesion.

Physical removal of toner

Figure 2 illustrates two mechanisms for physical toner removal under abrasion or scratching. It aims to show a layer of black toner printed onto a paper substrate and the two ways in which this can be compromised. Figure 2a shows layer splitting where toner – toner adhesion fails. This failure mode is common in abrasion testing and is not confined to toner layers – it has been noted in pigment based inkjet prints too.[13] By way of contrast Figure 2b shows a failure at the toner – paper interface, leaving a clean paper surface. This type of failure is illustrated in Figure 1.

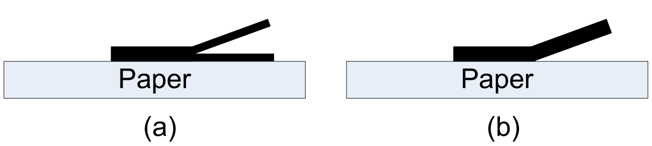

Figure 2(a) toner layer splitting (b) adhesion failure at the substrate interface

In order for toner printing to be acceptable in this market segment it is important to understand this difference in the eyes of a secure print customer. Toner layer splitting as illustrated in Figure 2a is much less of an issue for secure print as it still leaves a printed mark on the paper. Adhesion failure (Figure 2b) which leaves the surface clean of print is a much more serious issue, as is illustrated in Figure 1. This mode of splitting appears to be more common in electrophotography rather than inkjet systems which have a greater level of penetration into the paper.[2]

Relevant test methods for toner adhesion

As mentioned in the text around Figure 1 a customer test for this type of product is to scratch it with a finger nail and subjectively judge the result. The early part of this work looked at objective test methods to quantify this process. As will be shown below, this was unsuccessful and we resorted to subjective tests using finger nails.

There are various methods of testing toner adhesion referenced in the literature.[14] We evaluated 3 of these as a preliminary study for this work.

Tape pull testing

One method that is commonly used to monitor colorant adhesion is a tape pull test, monitoring optical density of the toner before and after adhesive tape stripping.[15] This method was found to give misleading results for this application. The reasons for this are illustrated in Figure 3.

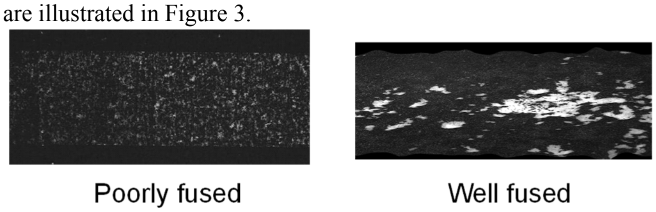

Figure 3Tape test results from poorly and well fused toner samples

Both samples were generated with the same printer and substrate but with printer settings modified to influence the degree of fusing. The poorly fused sample exhibited toner layer splitting as the toner – toner attachment was evidently worse than the adhesion to the paper. This is the type of failure illustrated in Figure 2a. However the well fused sample split most often at the toner – paper interface, like Figure 2b. This is probably due to the smoothness of the calendared paper surface which reduces toner adhesion. The result is that for this system the optical density measurements of the tape test a poorly fused sample can give a better result than well fused samples, even though the poorly fused is even easier to remove with finger nail scratch.

Abrasion testing

It is instructive to look at the experience of the Image Permanence community on toner adhesion. Print conservation for archives is an application area that is perhaps closer in requirements to security printing in that it deals with documents with a requirement for a longer lifetime. In this case the concern is for *inadvertent* damage caused through use rather than *intentional* damage with the intent to undermine the security of a document.[4] It has been noted for digital prints that abrasion tests are not a good indication of scratch sensitivity.[16] The work shows that for plain paper samples toner based prints perform well compared to other systems. However, the work in this paper illustrates that there are considerable weaknesses for secure print applications.

Scratch testing

This is the most obvious route to an evaluation test that would in some way mimic finger nail scratch. There is also an International Standard for scratch sensitivity of image forming materials in ISO 18922. However, it has been noted that this is not particularly useful for reflection prints.[15]

Scratch testing usually utilities a sharp stylus, either individually or as an array. The test methods usually look for surface damage or toner density reduction. However, for this application what actually is of interest is total toner removal.

As a result this work defaulted to a subjective test using a fingernail. This also proved to be much easier to communicate with customers.

Subjective evaluation of the scratch test.

After some initial testing of the method the results were subjectively evaluated into the following 5 categories.

Result	Evaluation category
Very poor. Total removal of the toner	✗✗
Poor. Almost total removal of the toner.	✗
OK. Significant damage but paper still marked.	✓
Good. Most of the toner retained but some damage.	✓✓
Very good. Little or no damage.	✓✓✓

Table 1 Evaluation criteria for the scratch test

Problems with modern toner printer design

A particularly important issue was noted early in this work with the trends in electrophotographic printer design. The scratch test performance of a number of modern electrophotographic printers is much worse than older models on this type of substrate.

It was noted that in some cases the adhesion of the toner to the smooth paper substrate was poor to very poor. The root cause appears to be the trend towards decreasing energy consumption in desktop printers.[14,17] This may well be a case where there is a divergence between the requirements of Security Printing and mainstream office use.

One key driver to energy reduction is the use of lower energy fuser units and the resultant use of softer toners.[7] It has been noted elsewhere that the key variables determining toner adhesion are nip pressure, fuser temperature and dwell time in the nip rollers.[18] As there is also market pressure for increasing printing speeds this is also driving the printers towards reduced fuser dwell times.

For mainstream applications using electrophotographic printing the reduction in energy use and printing time is probably a good trade for any reduction in adhesion. However, for Security Printing the trade off is different and will have a significant impact on printer model choice. For example, the international specification for visa printing stipulates that for print not showing significant penetration into the substrate there should be a "…strong bond between the material forming the image and the substrate".[19]

This change may also contribute to a further swing in favor of inkjet systems, particularly if pagewide inkjet can also deliver the printing speeds.

Printer testing

Three different printer models were used to illustrate this work. All three were of A4 scale commonly used in an office network environment. Printer #1 models were well used and printers #2 and #3 were new. All were filled with OEM toner.

Printer #1	Older (obsolete) model printer in commercial use in this market sector
Printer #2	Current model printer. Marketed as a commercial replacement for the obsolete model Printer # 1.
Printer #3	Current model printer. This apparently has a different design philosophy than Printer #2.

A test object was generated that consisted simply of lines of alphanumeric text to use as the subject for the scratch test. The evaluation criteria are as described in Table 1. The prints were also subjectively judged for appearance on the same scale. This was because at the poorest levels of fusing the printer transport mechanism seemed fully capable of removing toner too!

Printer #1 evaluation

The key variable evaluated with this printer was the fuser level setting. This model allowed user to access 5 levels of fusing capability. These are labeled 1 (lowest level) to 5 (highest level) in Table 2.

Fuser level	Appearance	Scratch test
1	✗✗	✗✗
2	✗✗	✗
3	✓✓	✗
4	✓✓	✓
5	✓✓	✓

Table 2 Results from the test of Printer #1

This printer was capable of delivering good looking prints but with marginally good toner adhesion. However, one of the practical problems with this unit was that the selection of fuser levels 4 and 5 resulted in a 25% increase in printing time. This was presumed to be due to an increase in the nip dwell time to increase fuser level.[18] The implication of this in practice was to produce an incentive for users under time pressure to decrease the fuser level, reducing printing time but decreasing the scratch resistance to unacceptable levels for secure print.

Printer #2 evaluation

This model again allowed user to access 5 levels of fusing capability and these are labeled 1 (lowest level) to 5 (highest level) in Table 3. Whilst this printer provides perfectly acceptable print quality on plain paper the adhesion was inadequate for this application on this secure substrate.

Fuser level	Appearance	Scratch test
1	✗✗✗	✗✗✗
2	✓✓	✗✗
3	✓✓	✗✗
4	✓✓	✗✗
5	✓✓	✗✗

Table 3 Results from the test of Printer #2

Indeed, at the lowest fuser setting simply tapping the print would remove most of the toner!

Printer #3 evaluation

This model again allowed user to access 5 levels of fusing capability through the print media options. Again these are labeled 1 (lowest level) to 5 (highest level) in Table 4.

This printer provides some very good results for this application with very good print quality and high scratch resistance on this secure substrate. The print times were also shorter than Printers #1 and #2, reflecting a different design philosophy that works well in this application space.

The somewhat anomalous mark for appearance at fuser level 3 was not a print quality issue. In this case the settings produced a significant amount of print curl, presumably due to the combination of time and temperatures utilized.

Fuser level	Appearance	Scratch test
1	✓✓	✗
2	✓✓	✓
3	✓	✓
4	✓✓	✓✓✓
5	✓✓	✓✓✓

Table 4 Results from the test of Printer #3

Other observations pertinent to Security Printing

As a part of this work a large number of prints were produced over an extended period using a number of printers of the same model of varying history. There were two further useful observations that came from this study.

1. Variations in adhesion over a long print run. It has been noted that some systems show a reduction in image density over a few thousand prints.[20] We noted a similar variation in scratch susceptibility. A fresh cartridge of toner produced significantly higher scratch resistance than one that was 75% exhausted.
2. Provenance of the toner supply. A partially used non-OEM toner cartridge was tested. In this case the prints produced had significantly reduced scratch resistance. This is another practical example of the need to secure the supply lines for *all* consumables in Security Printing applications.

System modification for Security Printing

It can be seen from Tables 2-4 that electrophotographic printers are capable of generating a wide variation of print security on these substrates. In response to this ways in which to mitigate this variation was sought.

One option explored was the use of bespoke adhesion promoters applied onto the paper surface. The aim here was to counter the reduction in adhesion from the calendared surface of the paper.

Some initial results on this with printer #1 are illustrated in Table 5. Comparison with Table 2 shows that the gains in scratch resistance can be significant.

Fuser level	Appearance	Scratch test
1	✗✗	✗
2	✓	✓
3	✓✓	✓✓
4	✓✓	✓✓✓
5	✓✓	✓✓✓

Table 5 Results from the test of Printer #1 with adhesion promoter

Similar gains can also be achieved with printer #2, as illustrated by a comparison of Tables 2 and 6.

Fuser level	Appearance	Scratch test
1	✗	✗✗
2	✓	✓
3	✓✓	✓
4	✓✓	✓✓
5	✓✓	✓✓

Table 6 Results from the test of Printer #2 with adhesion promoter

This is not an ideal solution. It adds a production step (and hence cost) and has other operational ramifications too. It should be also be noted that this extra layer on the surface is not required for inkjet printing, an additional opening for a change in technology.

Toner printing secure documents in the future

It has been shown that toner systems of different generations and manufacturers produce markedly different results when used in this security printing market, a difference not as apparent on traditional plain paper substrates. This illustrates the diverging nature of the applications for these engines. As a result electrophotographic printing faces increasing challenges in this market sector. Market forces in the wider print applications space are pulling printer development on a path that in general diverges from secure document production. At this moment in time the major advantages of this technique are as follows.

- Time per print – simple print speed. However, as shown in the experimental section above some of this must sometimes be sacrificed to gain adequate toner adhesion.
- Electrophotography is a dry process. This is a significant advantage over inkjet technologies, particularly on these smooth and calendared substrates where liquid inks can have significant dry times.

There are still potential electrophotography opportunities in security print for innovative ideas in printers and materials.

- Print engines of both desktop and enterprise scale that can produce high adhesion on calendared substrates.

- Materials that can be used to cause the scratch tampering of toners either apparent or more difficult.

The challenge from desktop inkjet

Desktop inkjet occupies a significant position in the personalization of secure documents. The most significant advantage is the penetration that can be achieved using liquid inks. This makes it much harder to fraudulently alter the print as the colorants are now in the depth of the paper.[2] This penetration is seen as a significant feature by the regulatory authorities.[19]

However, desktop inkjet systems do have some disadvantages.

- Some of these documents are of unusual size and format. This can prove to be a significant challenge to the transport mechanisms of some inkjet printers.
- Dry time and smudge resistance can be an issue, particularly with pigmented inks. During the early stages of this drying process the documents are more open to fraudulent alteration.

Desktop print systems that can provide solutions to the above issues can again find interest in the Security Printing sector.

The potential of page wide inkjet

In the medium term this sector also faces a challenge from page wide inkjet printing. If these units can produce the speed of electrophotographic printers while keeping drying times low there is great potential for these units to take share in this market.

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Alan has 30 years experience in printed hard copy and a background in photography and image science. Alan previously managed R&D and Technical Services groups active in inkjet application development. For 4 years he worked on printing and optics consultancy projects that often crossed over into security applications. In November 2008 he joined 3M in the UK as Technical Development Manager, specializing in print solutions for high security documents such as passports and identity cards.

Alan has a BSc in colorant chemistry and a PhD in instrumentation, both from the Department of Chemistry at the University of Manchester. He has served as session chair, short course instructor, and presenter at a number of IS&T conferences such as NIP, DF, Archiving, and ICIS. He is President of the IS&T.