Coated Media for Digital Fabrication: Lessons from the Photo Industry

Alan Hodgson; Alan Hodgson Consulting; Macclesfield, Cheshire, United Kingdom

Abstract

For over 150 years the photographic industry has been coating media for imaging applications. This experience spans both rigid and flexible media and encompasses many issues pertaining to the adhesion of material to these substrates. For many of these years work concentrated on swellable polymer layers but with the emergence of inkjet in photo imaging this broadened to cover porous coatings too.

The paper covers the experience that may be transferable to media for Digital Fabrication. By way of example, it covers the coating of swellable layers on glass and flexible substrates and the variables that were routinely used to influence the physical and printing characteristics. It also covers the issues of printed inkjet spot morphology and the ways in which the characteristics of the coatings can influence this.

The paper also examines some applications where these types of coated media could be particularly pertinent.

Introduction

At the first of these Digital Fabrication conferences in 2005 it was evident that a large amount of work was taking place using micro-dispensing techniques such as ink jet to deposit liquids onto a wide variety of substrates. For rigid substrates glass seems to be a common choice but for flexible substrates a wider selection of media were finding applications. For mass production some form of paper could be important. For other applications flexible plastic films may well be used.

These are all substrates where the photographic industry has many years of experience. The aim of this paper is to outline some of the areas where this experience could find application to the emerging Digital Fabrication technologies.

The paper can be read in 4 parts, in roughly historical order. The first covers the use of glass plates as a substrate and the second the use of coated layers to modify the characteristics of a substrate. The third covers the use of fluid receptive layers for ink jet media and the fourth the use of microdensitometry as an evaluation technique for coated systems.

Glass as a substrate

Glass plates play a major part in the early history of photography[1]. Although the introduction of film base in the late 1890s precipitated the decline of glass plate production new photographic glass plate products continued to be introduced through to the mid 20th Century[2], the later products being mainly for specialist technical applications. There are a number of technical reasons why glass was the substrate of choice and as many of these are still pertinent for Digital Fabrication applications they are worth listing here.

Key technical attributes of glass

Glass has a number of very useful properties as a substrate and these properties are summarized below.

1. Glass has optical properties that are particularly suited to some applications. It can be manufactured to be especially clear, colorless and low in light scatter. This is important in applications such as displays where the substrate becomes a part of the optical assembly. Glass can also be manufactured free of birefringence effects, important in applications that would involve polarized light.
2. Glass can be ground, polished and figured to a precise shape or flatness.
3. Glass is dimensionally stable. It undergoes very little change in dimensions with humidity or during chemical processing. As a result it finds applications in scientific imaging techniques such as X-ray topography where precise measurements may be made on the plates after aqueous processing which need to be equated to positions or angles in the original exposure.
4. Glass is a rigid substrate and will not cockle like some plastic products. For example, the rigidity of the glass substrate lends itself to precision work making photo masks for semiconductor fabrication.

However, glass can also be manufactured thin enough to be bent to a precise curve. This has been used to great effect in some analytical[3] and astrophotography[4] applications.

5. Glass contains no small, labile molecules. There are no volatiles that could leach out in a vacuum. This is important in high vacuum scientific imaging such as in the far UV where the requirement to de-gas a film product can be a significant problem. Similarly, glass can provide a chemically inert base for other chemical processes that can be sterilized and aggressively cleaned. This could be important in future biological applications.

Balanced against these advantages there are however a number of problems in the use of glass. In addition to the obvious ones of weight and fragility there are issues to be addressed in terms of creating a uniform coating and ensuring satisfactory physical properties such as adhesion and abrasion resistance. A major variable in the control of these characteristics is the wetting characteristics of the glass, an issue that is also faced in Digital Fabrication applications.

Coated glass plates in photography

The experience of many years saw the development of various technologies to coat photographic emulsion layers onto glass to high levels of quality and reproducibility. The original process of pouring molten emulsion from a teapot onto cold glass was replaced by automated coating machinery[2]. In particular the technical issues involved in ensuring the requisite level of adhesion between glass and the coated layers was the subject of considerable work. The issue of the non uniform thickness of emulsion coating towards the edge was also dealt with, in some cases by cutting away significant areas from the edge of the plate but in others by considered and judicious adjustments to the coating conditions.

Glass plates in Digital Fabrication

The key attributes listed earlier in this paper that made glass attractive for photographic use are still of value in Digital Fabrication. Also, the knowledge and technical capabilities developed from years of glass plate technology are applicable to some of the emerging applications.

Over the last few years we have seen the appearance of flatbed inkjet printers that are capable of printing onto rigid media. Whilst these devices are capable of printing onto glass plates this has mainly been restricted to creative printing applications. Process development systems designed for Digital Fabrication are now appearing, capable of printing onto glass substrates[5]. In addition advances in print head design are giving access to different jettable fluids[6]. The key enabling technologies are now coming into place for rapid advancement in this field.

Much of this work is still in the R&D phase and the same key attributes listed earlier in this paper that originally made glass attractive for photographic use are of value for this purpose. Prints on glass substrates are being used to develop processes for fabrication in hybrid printing systems[7] and electronic memory devices[8]. Glass has also found use as a test bed for materials development of metallic inks for the fabrication of conductors in printed electronics[9]. In addition to these development activities, some early applications already exist. As an example, fabrication techniques using glass substrates have been shown to be effective in catalyst screening[10].

The R&D use of glass plates in Digital Fabrication seems set to continue but the more lucrative and high volume sales await production scale applications. Glass plates are currently the substrate of choice for flat panel display fabrication as it can withstand the temperature conditions of the process and has the requisite dimensional stability[11]. Whilst much effort in display technology and printed electronics will go into work on flexible substrates market research[12] indicates that $183 million of glass substrates will be consumed by the printable electronics industry in 2013.

One promising area that Digital Fabrication will undoubtedly move into is the manufacture of optical devices. Some early work has shown that microlens arrays can be produced by depositing polymer droplets onto a substrate[13]. An interesting extension of this is the manufacture of microlenses by ink jetting drops of solvent onto a polymer substrate and allowing the wetting and subsequent evaporation of the drop to deform the surface[14]. This is a well known phenomenon in the photographic industry as it leads to an unwanted artefact on films known as drying marks[15]. As a result there had been a considerable amount of work done on technologies to modify and control this phenomenon which could find use in optical fabrication applications.

Biochemical applications may also play a part in the future. Traditional gelatin coatings may prove to be an interesting medium for biochemical processes dispensed by these new Fabrication technologies.

The use of coated layers to modify substrates

The photographic industry has often used coated layers to modify the characteristics of a substrate in addition to the layers that record a photographic image. A commonly used technique was to coat a *substratum* or subbing layer onto the substrate before the main coating process took place. The main purpose of this layer was to ensure an adequate adhesion of the photographic layers to the substrate and these subbing layers were often coated off line from the main coating process.

One common method was to coat a thin gelatin layer containing a cross linking agent. This hardened this layer and promoted adhesion to the substrate. This layer then provided a suitable surface on which to place the primary functional layer. A simple formula used in autoradiography[16] is shown in Table 1.

Gelatin	0.5g
Chrome alum ($K_2SO_4.Cr_2(SO_4)_3.24H_20$)	5.0g
Distilled water to 1 Liter	

Table 1 A simple subbing solution

One interesting variant on this the use of a sacrificial subbing layer to produce a stripping film[15]. These types of products found application in graphics arts and autoradiography[16]. They were fabricated with a soluble layer between the substrate and the main image forming layers. This allowed the final coated product to be floated off the substrate and transferred to another system.

These technologies may find application in Digital Fabrication. Coated layer technologies are capable of modifying the wetting characteristics of a substrate and hence the inkjet printed dot morphology. Examples of this are given below. Stripping film systems could also be of interest as they would allow a fabricated assembly to be released from the substrate at a suitable point in the process.

The effect of ink receptive layers

As the photo industry made the transition from analogue (film based) to digital imaging new types of hard copy media were required. One important segment of this market is inkjet media and as a result new coated assemblies are developed to maximize the potential of this output system. In order to optimize photo image quality of the resultant prints significant effort goes into controlling the size and shape of the printed dot. As dot sizes decreased and printing speeds increased ink jet photo media manufacturers have adapted technology to maximize the benefits that these changes bring.

Figure 1 shows a picture of a CMYK dye based inkjet print taken down a microscope. The image is built up of a large number of small colored (or black) dots. The reflection density and color of the image depends on the number and mix of these dots per unit area. In some cases and particularly in low density areas the dots are individual and surrounded by white space. In other cases the dots overlap.

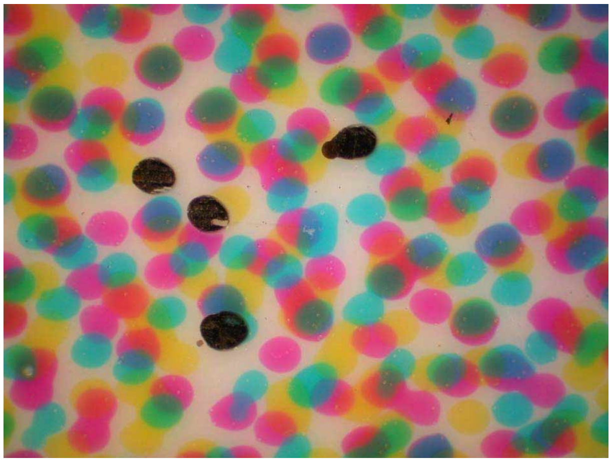

Figure 1 A magnified CMYK inkjet image

Figure 1 also shows the dots to have a sharp and nearly circular profile. This need not be the case in practice, as illustrated below.

Factors influencing the morphology of the printed dot.

When a drop of inkjet fluid is printed on media it has been shown[17] that there are 3 phases in the process of forming the final printed dot.

1. Inertial spreading. The fluid droplet which may be of perhaps 5 to 100 picolitres hits the media at around 10 m/s. The droplet spreads due to its own inertia to an extent that is mainly governed by the kinetic energy, viscosity and the surface tension of the drop. This latter property is one that can be easily manipulated in the fluid formulation to modify the final dot diameter[18].
2. Absorption. The droplet comes to rest at a quasi-equilibrium position governed by the wetting characteristics of the media by the fluid. On a smooth, isotropic medium this would be expected to result in a drop of near circular horizontal profile. However, when dots are printed with any level of overlap ink spreading from one drop into another can take place[19]. Examples of this effect can be seen in Figure 1.
   However, many desirable substrates are not isotropic and have significant surface features that influence the form of the printed drop. The result is printed dots that are far from circular[20].
3. Evaporation. The final stage of the process is the evaporation of the printed liquids. It is generally the case for photo inkjet media that this takes place at a much slower rate than absorption. As it is the balance between absorption and evaporation that drives the final dot shape it is usually the absorption step that is the main driver for dot morphology. It has been shown[17,19] that this results in an optical density profile for the printed dot that is roughly parabolic in shape. This can be envisaged as the dome shaped drop on the surface being sucked down into the media as illustrated photographically in the literature[17].
   When printing onto a non absorbing medium such as glass or metal the process is dominated by evaporation. In this case the drop profile is not parabolic but due to capillary processes dries into a toroid or donut shape sometimes known as the "coffee-ring" effect[21]. In addition, the formation of a "cake" of particles at the substrate – droplet interface can in some cases result in the absorption of liquid being retarded, even on porous media[17].

One practical method of evaluating substrates for their behavior to ink is by dynamic contact angle measurement[20]. Ink spreading in particular can result in lower sharpness from the printed image[22].

Coated layers have evolved for photo inkjet media to control the parameters of dot morphology. This knowledge may be of use in future Digital Fabrication applications.

Inkjet dots as 3 dimensional objects.

It is easy to forget when looking at reflection light microscope imagery such as Figure 1 that there will also be a depth perspective to the image recording. This is revealed by examining thin sections through dots on substrates by light microscopy, as illustrated by Figure 2 from a previous publication[23].

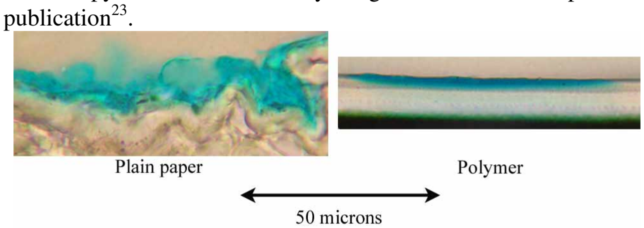

Figure 2 Cross section of a dye ink dot on 2 different media

In some cases retaining the inkjet fabricated layer on the surface with a sharp boundary with the substrate will be the objective. In other cases it may be useful to have significant penetration into the substrate. Both examples exist for photo inkjet media applications and coated surfaces have evolved to facilitate this.

Microdensitometry as an evaluation tool

Microdensitometers were traditionally used to analyze image structure in photographic images[24]. In the majority of cases work was done on photographic films using transmission optics. However, the technique can equally well be applied to opaque systems using reflection optics, including digitally printed systems[25]. The options of light and dark field illumination and numerical aperture combined with independent illumination and collection aperture settings make potent combinations for the analysis of reflection images.

A microdensitometer as illustrated in Figure 3 was designed to measure optical density on a microscopic scale. In practice, it can do rather more than that task. It can produce reproducible quantified information on materials that can be imaged optically. Information can be generated on spatial positioning such as line widths and placements and optical characteristics. The imaging versatility of such a measurement tool can allow a wide variety of details to be imaged and quantified[25].

Figure 3 A Perkin Elmer PDS 1010A microdensitometer

Conclusions

The photographic industry has much to offer Digital Fabrication. There is long experience in the use of glass as a substrate and of the use of coated layers to modify the characteristics of surfaces for coating. More recently there is the use of fluid receptive layers for ink jet media. Finally, microdensitometry is an evaluation technique that has the versatility and accuracy to make significant contributions to the understanding of Digital Fabrication issues.

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Author Biography

Alan received his BSc in chemistry followed by a PhD in instrumentation from Manchester University in 1982 and began work as an Image Physicist with ILFORD Imaging. After a number of technical support and Sales & Marketing roles his final role was Technical Services Manager at the head office in the UK, covering both traditional photo and emerging ink jet technologies. In 2004 he left to become an independent consultant on optics and non-impact printing. He is a member of the IS&T, the Royal Photographic Society Imaging Science Group and the Institute of Physics