WHEN SCIENCE MEETS PRINTING

Peter Kiddell gives the reasons why understanding adhesion is essential

Peter Kiddell

Most of us go through our careers in print trusting that there is an ink system available that will perform as we want on the substrate. When we look at a printing process we see the equipment the substrate, and the wet then dry ink. What impresses us most is the machinery because it is the biggest part of the process. Then as printers we consider the ink we should use, how we will dry and cure that ink and the condition of the substrate before during and after the printing process. When we need to determine the quality of the finished print we use our own eyes, magnification, scratch testing, abrasion resistance testing and other electrical and physical tests depending on the application.

Machinery manufacturers emphasise speed, size, quality and cost per print. At exhibitions such as FESPA we see amazing designs on a vast range of substrates with salesmen speaking about the most recent developments of their equipment and its technical superiority to the competition. Very rarely do you hear of people speaking about what is actually happening in the printing process. To most of us printing is like watching an IPL cricket match without any understanding of the laws of cricket – just players running around a field, and the crowd getting very excited about their antics. In print a machine converts substrate from a plain finish to something that either looks attractive, provides information or serves some other purpose.

PHYSICAL AND CHEMICAL LAWS

The question that needs to be answered is: "What are the physical and chemical laws that govern the printing process?" Once we have an understanding of these then, and only then, can we recognise how we can influence the printing process. There is a cause for every problem that occurs. Often it is a matter of incorrect machine set up or poorly maintained equipment. When it comes to a break-down in adhesion of ink to the substrate or deterioration of the ink film then the issues are likely to be much more obscure.

It is rare that there is a fault in the actual formulation of the ink when it comes from the supplier. How it is stored or mixed by the printer is much more likely to be the cause of problems. It may simply be the wrong ink for that particular application or not dried and cured correctly. If you are buying ink from a reputable supplier there will be chemists carefully formulating the ink and skilled production staff maintaining quality from batch to batch. If you are buying the cheapest ink from an obscure manufacturer then there may be issues of formulation and production errors. If the ink quality is compromised you are in real trouble and you have no chance of controlling the process or predicting the printed result.

Before we look more deeply into this topic let me make it clear I am not a scientist and this is not a scientific article. I am a printer who has to understand the science of print to get the best from the process. You notice that up until now I have not specified a particular process because what is to be discussed is at an atomic and molecular level which makes specifying the particular process irrelevant. Whether it is screen-printing, digital printing, pad printing, lithographic printing, flexographic printing, etc, the same rules apply.

RECOGNISING AND AMELIORATING THE VARIABLES

Surface chemistry is an area of science that influences every aspect of life from simple bacteria to the most advanced theories in quantum mechanics. If it is in the physical universe surface chemistry will be involved. So, having built it up it is only fair to say that the theories that govern the topic are theories not facts. Every formula that has been produced has unknown variables. As printers our aim has to be to recognise where the variables are and ameliorate them. We are helped by the fact that most printing is an optical illusion, for example process colour is made up of cyan, magenta, process yellow and process black. When printed in dots of a particular orientation and size and viewed from a suitable distance we see a full colour image. Of course this optical illusion applies to digital display technology where the transmitted colours are green, red and blue, but it is not digital display screen technology that is the focus of this article. It is in industrial printing applications where printing is part of a manufacturing process that the optical illusion aspect is irrelevant. The physical and chemical characteristics of the dried and cured film are the key factors. For industrial applications the drying and curing phase can be crucial in the condition of the finished film. This is a whole new topic area that will be considered separately in another article. The same principles apply to process

Figure 1: Dyne pens (Courtesy of www.dynetechnology.co.uk)

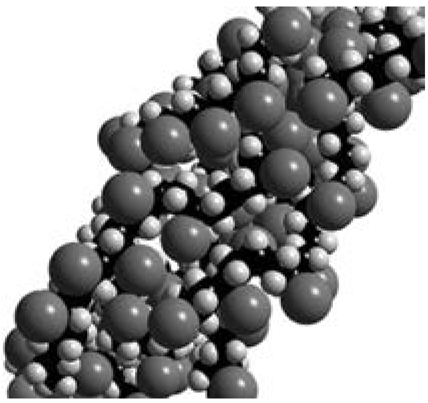

Figure 2: Non-polar – polypropylene

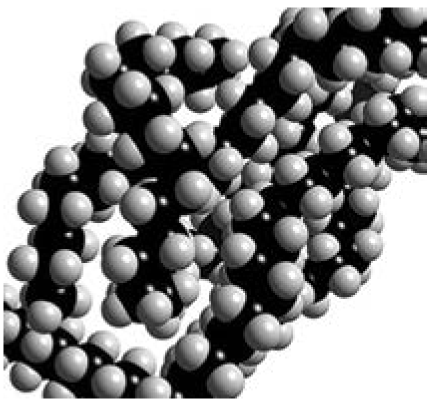

Figure 3: Polar – poly vinyl chloride PVC

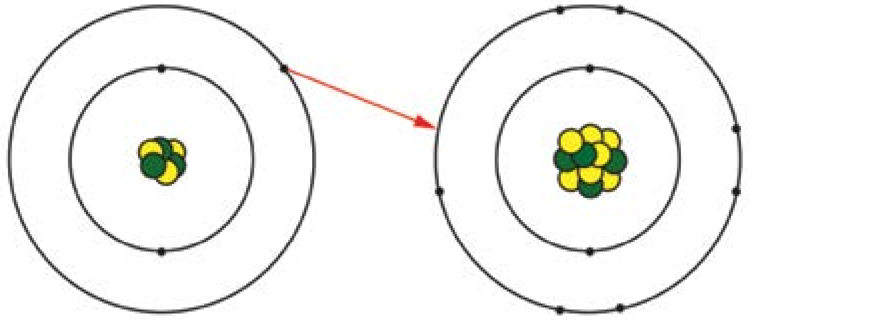

Figure 4: Ionic bond

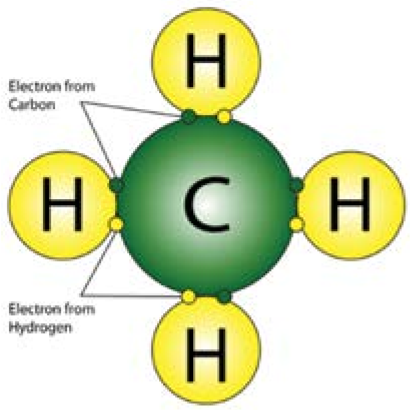

Figure 5: Covalent bond

and line colour printing so don't stop reading just because your business is not in the industrial printing sector.

A COUPLE OF DEFINITIONS

Cohesion: the condition where molecules of the same material are attracted to each other

Adhesion: the condition where molecules of different materials are attracted to each other.

For ink to adhere to a substrate the forces creating adhesion on the substrate have to overcome the forces of cohesion in the ink. Molecules of a liquid will naturally be attracted to each other and, in a zero gravity situation, demonstrate this by forming a perfect sphere.

For adhesion to occur the ink must be able to come into close contact with the substrate; in printing we know this as 'wetting' the substrate. This wetting is to do with the relationship between the surface energy of the substrate and the surface tension of the ink. The surface energy of the substrate must be higher than the surface tension of the ink. Again in print we measure or indicate this with 'dyne pens' or contact angle measuring devices (Figure 1).

The difference should be better than 10 dyne cm (mN/m.) Sometimes this difference occurs naturally but in other cases it is necessary to pre-treat the substrate to increase its surface energy. This is done using flaming, corona discharge, plasma treatment or occasionally, but not recommended, chemical pre-treatment. If this form of pre-treatment is the careful application of a primer, for example in printing certain textiles, then it is quite acceptable. It is the application of aggressive solvents in an uncontrolled fashion that is to be avoided. For some substrates, which naturally are not wetted by the ink because of their low surface energies, such as polyethylene and polypropylene, there are inks which can be formulated with very low surface tensions that will adhere to these substrates. These special inks are limited in application as they are not always resistant to water and other solvents.

These polyethylene and polypropylene are also known as non-polar as opposed to polar, and examples of such materials are shown here.

Polar	Non Polar
PVC	Polypropylene
Styrene	Polyethylene
ABS	PTFE
Acrylic	EVA
Polycarbonate	PET

A non-polar material means that there are not the opportunities for molecules from other materials to bond, because there are no free electrons to become attracted to (Figure 2).

A polar material (Figure 3) has a type of covalent bond between two atoms in which electrons are shared unequally. Because of this, one end of the molecule has a slightly negative charge and the other a slightly positive charge. (See below: Chemical and Dispersive Adhesion.)

Having achieved satisfactory wetting of the substrate by the ink the process of adhesion then has to occur. These are:

CHEMICAL ADHESION

Where atoms of the two materials swap or share electrons (known as ionic bonding or covalent bonding, respectively). (Figure 4 and Figure 5).

Continued over

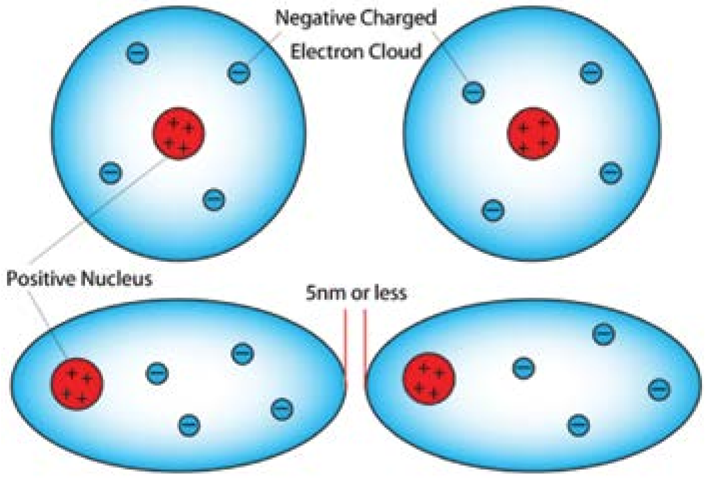

Figure 6: Van der Waals forces

Figure 7: Diffusive adhesion

Figure 8: Mechanical adhesion

DISPERSIVE ADHESION

Van der Waals forces – the attraction between two molecules, each of which has a region of slight positive and negative charge (Figure 6)

DIFFUSIVE ADHESION

This may occur when the molecules of both materials are mobile and soluble in each other (Figure 7).

MECHANICAL ADHESION

Adhesive materials fill the voids or pores of the surfaces and hold surfaces together by interlocking (Figure 8).

From the above assertions it can be seen that adhesion can be affected by the exchange of electrons between atoms (chemical), the effect of static electricity between molecules (dispersive), the solvent qualities of the ink (diffusive), and the roughness of the surface of the substrate (mechanical).

It must be remembered that the adhesive properties apply to the relationship of the ink to the substrate whilst the ink is still a liquid. But, once it has dried and cured, there is another key characteristic that is interfacial tension.

INTERFACIAL TENSION

Once the bond between the ink and the substrate is formed there is another force that will affect the integrity of that bond. This is interfacial tension. When two materials come together they give up their surface energies to form an interface. The adhesive energy is that which holds the materials together whereas the interfacial tension is leftover from the original interface that works against the adhesive energy. It is this that determines the likelihood of the bond breaking if it subjected to physical stress. An example of this is when an ultra-violet cured ink breaks away from the substrate if the ink film is bent or cut through.

The relationship between ink and substrate is unlike most other chemical reactions. In the first instance the ink is often a mixture of liquids and solids that has been attracted to the substrate for the printing mechanism to take place. Once in contact with the substrate and still liquid it is needed to stabilise and not continue to flow. The ink then changes from a liquid to a solid and has to form a permanent bond with the substrate. All during this time the electrons on the atoms of the materials within this material combination are moving between atoms changing the forces of attraction and repulsion. The volume of ink changes and inks and substrates expand and contract at different rates. The addition of heat energy accelerates these changes.

HOW TO ACHIEVE GOOD ADHESION

The question to be answered is what can be done to have the best chance of achieving good adhesion?

- Make sure the substrate is clean before printing.
- Ensure that the substrate is at the temperature of the print shop before printing.
- Mix the inks precisely by weight.
- Try to use as many of the forms of adhesion as possible to form the final bond.
- The two most predictable are diffusive adhesion and mechanical adhesion.
- If pre-treatment is required to achieve chemical and dispersive adhesion be aware of the characteristics of the pre-treatment methods.
- Take advice from your ink supplier.
- Never use inks that are out of date.
- Ensure that drying and curing methods are set correctly and the time required for a complete cure is kept to.
- A roughened surface will provide a better bond than a gloss surface.
- Generally the application of heat will improve adhesion.
- Where solvents in the ink can dissolve/soften the surface of the substrate a better bond is likely.

Now you have a better understanding of adhesion you are a lot closer to having a predictable bond between the substrate and the ink. Whether an ink will withstand mechanical abrasion, be chemical resistant, will maintain its colour over time or be safe to use in contact with foodstuffs, is another area for consideration. The finished chemistry of a dried and cured ink film is the key characteristic in this context and is more predictable than the constantly changing relationship of the liquid ink and solid substrate.

Whether digital or analogue printing, until you have some understanding of the science behind printing only then will you be able to continuously improve the process. ■

This article originally appeared as a feature on FESPA's website at www.fespa.com

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