Surface Energy & Self-Adhesive Labelling

Substrates and adhesives in balance
Contents

1. Optimal adhesion on high and low surface energy substrates ........................................3

2. Wet-out ....................................................................................................................................4
   2.1. The precondition for adhesive success ..................................................................................4
   2.2. High or low? Surface energy in dynes ..................................................................................5
   2.3. Where does surface energy come from? .................................................................................6
       2.3.1. Electron sharing and polarity .........................................................................................6
       2.3.2. ‘Polar’ and ‘non-polar’ substrates explained .................................................................6
       2.3.3. Surface energies in balance..............................................................................................6
       2.3.4. Dipoles, attraction between molecules, and surface energy ........................................7

3. Engineering adhesives .............................................................................................................8
   3.1. Acrylic dispersion adhesives ..................................................................................................8
       3.1.1. Modification for low-energy substrates ..........................................................................8
   3.2. Cross-linked adhesives ..........................................................................................................9
       3.2.1. UV-cured and catalyst activated solutions ........................................................................9
       3.2.2. Challenging conditions and their influence on adhesive selection ................................10

4. Identifying the right adhesive ....................................................................................................11
1. **Optimal adhesion on high and low surface energy substrates**

Self-adhesive label printers are well aware of the impacts of a label material’s surface energy on ink anchorage, and the effects this has on the overall print result. This same phenomenon influences the way adhesives bond labels to substrates.

While printers can use corona treatment or topcoats to adjust the surface energy of the printing substrate, the same option does not exist for the labelled substrate. Good adhesion can only be achieved by developing the right properties for the adhesive.

It is important to get the surface energies of the adhesive and substrate correctly balanced to ensure excellent label performance. Get this right, and without the inefficiencies of using an adhesive that is overengineered, and you have an optimal match to your requirements.
2. Wet-out

2.1. The precondition for adhesive success

The term ‘wet-out’ describes the flow of the adhesive over the substrate to be labelled. Good wet-out is necessary to achieve full adhesive contact and bonding over the surface area of the substrate. Wet-out occurs when the substrate has a higher attraction for the adhesive than the adhesive has to itself.

The attraction between the adhesive and substrate is determined by their relative surface energies. The surface energy of the adhesive must be equal to or lower than the surface energy of the substrate to achieve maximum contact and sufficiently strong bonding. It follows that the higher the surface energy of the substrate, the less challenging it is to accomplish good adhesive wet-out.

**Incomplete wet-out:**

The beaded globules represent the adhesive, which has a greater attraction to itself than to the substrate. The substrate has lower surface energy than the adhesive.

**Successful wet-out:**

When the adhesive is attracted more to the substrate than to itself, it flows over the substrate to maximize contact and bond more strongly. The substrate has higher surface energy than the adhesive.
2.2. High or low? Surface energy in dynes

As a general rule, the lower the surface energy of the substrate, the more challenging it is to achieve good adhesive wet-out and bonding – and the greater the complexity required of the adhesive formulation.

More complete wetting occurs when the substrate has higher surface energy than the adhesive. Metals, glass and even comparatively high surface energy plastics like ABS and PET are less challenging to adhesive wet-out than low surface energy substrates like PE and PP plastics.

Surface energy is measured in ‘dynes per centimetre’. UPM Raflatac considers 40 dynes/cm to be the approximate boundary between low energy and high energy substrates from the self-adhesives perspective.

<table>
<thead>
<tr>
<th>Typical labelling substrates and their surface energies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High energy or ‘polar’ substrates (greater than 40 dynes/cm)</strong></td>
</tr>
<tr>
<td>Copper 1103</td>
</tr>
<tr>
<td>Aluminium 840</td>
</tr>
<tr>
<td>Zinc 753</td>
</tr>
<tr>
<td>Stainless steel 700-1000</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Low energy or ‘non-polar’ substrates (less than 40 dynes/cm)</strong></td>
</tr>
<tr>
<td>PVC 39</td>
</tr>
<tr>
<td>Polyethylene (PE) 31</td>
</tr>
<tr>
<td>Polypropylene (PP) 29</td>
</tr>
<tr>
<td>Acrylic 38</td>
</tr>
<tr>
<td>Teflon® 18</td>
</tr>
</tbody>
</table>
2.3. Where does surface energy come from?

2.3.1. Electron sharing and polarity

Atoms have positively charged nuclei which exert attraction on the negatively charged electrons that rotate around them. When atoms bond together as molecules, they share electrons — but the electrons are not always shared equally.

This unequal sharing of electrons in molecules leads to the formation of an electric dipole, as if each molecule has a positive and a negative side. Opposites attract. This polarity is a key attractive force which bonds molecules together in solids — including the solids that interest us as labelling substrates.

2.3.2. ‘Polar’ and ‘non-polar’ substrates explained

Molecules that make up solids such as metals tend to have more, unequally shared electrons and therefore greater polarity compared to the hydrocarbon molecules which form polymers like PE and PP, for example. That is why metals tend to be more dense and have higher melting points than these plastics — there is a stronger attraction between the molecules in the solid.

On the surface of a solid, however, the bonds that run through the bulk of the solid are disrupted. On this exposed area, there is an excess of the attractive force that pulls the solid together — surface energy.

The level of surface energy depends on the intensity of the dipoles pulling together the molecules that form the solid. This is why we tend to speak of ‘polar’ substrates like metals and glass, and ‘non-polar’ substrates like PE and PP.

It is not true that PE and PP have no surface energy at all, of course, but that the surface energy is so low, below approximately 40 dynes, as to make attraction between an adhesive and the substrate a challenge.

2.3.3. Surface energies in balance

Is the surface energy of the substrate great enough to attract the molecules at the surface of the adhesive? Or is the same force of attraction operating between the molecules in the adhesive so high, that the adhesive resists attraction to the substrate?

These are the big questions concerning adhesive wet-out and bonding. The solution comes down to a balance of relative surface energies.
2.3.4. Dipoles, attraction between molecules, and surface energy

The concept of dipoles is represented in this simple model of H$_2$O molecules as water. When one oxygen atom and two hydrogen atoms come together to form a single molecule, the way they share electrons unequally creates an electric dipole, as if each molecule has a + and - side. These opposite and therefore attractive charges bring the molecules together as water, and the same principle applies to solids. On the surfaces of liquids and solids, the molecules are short of ‘partners’, so there is an excess of attractive force – this is surface energy.
3. Engineering adhesives

The surface energy of the labelled substrate has a fundamental influence on the complexity of the adhesive formulation. The adhesive needs to be engineered for an appropriate balance of tack and sufficiently low surface energy relative to the substrate. The requirements of certain end-uses must also be taken into account.

Acrylic adhesives are discussed here to explore the links between substrates and adhesive engineering, but the same general logic regarding complexity applies equally to rubber hotmelt adhesives.

Acrylic adhesives have remained unchanged for a long time in their basic formulation. They comprise two key components: an acrylic polymer (based on butyl acrylate and/or 2-ethyl-hexyl acrylate), and compatible tackifiers to improve their properties of adhesion. The tackifiers are based on a rosin acid or rosin ester, derived from aged tree stumps, tree sap or by-products of the papermaking process like tall oil.

3.1. Acrylic dispersion adhesives

Acrylic dispersion adhesives are the UPM Raflatac adhesives with the prefix ‘RP’. UPM Raflatac has used these water-based adhesives from its earliest days, and was one of the first companies to actively develop them for use with self-adhesive laminates.

These adhesives are variously referred to as water-based, water-borne or acrylic dispersion because the polymer with tackifiers is carried by water onto the siliconized label stock liner. After coating, the water is evaporated and the label face is applied to complete the self-adhesive laminate.

Water-based acrylic adhesives are modifiable in various ways to offer good properties of adhesion on substrates with a range of surface energies – including materials with a low dynes/cm value such as PE and PP. They have some heat resistance, good UV-stability and clarity, and good water resistance after the label has been applied to the substrate.

3.1.1. Modification for low-energy substrates

High energy surfaces such as glass are straightforward surfaces for labelling with these adhesives, and relatively little modification is required to the basic adhesive formulation. But for labelling on low surface energy substrates like PE and PP packaging films, it is necessary to further engineer the acrylic dispersion adhesive by introducing additives which reduce its surface energy – so that it is attracted more to the substrate than to itself.
Reducing the adhesive’s surface energy encourages a good wet-out to maximize the area of contact for bonding. Additional tackifiers may be added to restore losses in initial tack caused by the use of additives, further increasing the complexity of the formulation.

3.2. Cross-linked adhesives

A side-effect of the additives used to reduce the surface energy of all acrylic adhesives is reduced cohesion. Cohesion describes the internal strength of an adhesive.

Cross-linking locks together the polymers in an adhesive, increasing its internal strength (cohesion). This increases the adhesive’s resistance to heat, chemicals, UV-light, water and ageing.

This reduced cohesion plus the addition of tackifiers degrades the adhesive’s temperature resistance, which also means it is less resistant to bleeding at higher temperatures. Reduced cohesion also makes the properties of adhesion susceptible to weakening when in contact with oils and chemicals, weathering and prolonged exposure to water.

There are a wide variety of labelling applications where the effects of this reduced internal strength are undesirable. Examples include personal care labelling on low-energy substrates such wet-wipes packages, and home care end-uses like sealing labels on disposable plastic air-fresheners, where resistance to water, oils and chemicals is essential.

In particular applications, a deliberate increase in cohesion is necessary to improve the adhesive’s overall stability and various resistances. By far the biggest end-use segment is durable labelling, where the label and the information it carries need to last for an extended duration when subjected to a range of exposures – for instance on outdoor, domestic and electronic appliances, and in automotive and industrial end-uses.

The answer is to chemically cross-link the polymers in the adhesive, locking them together to vastly improve the internal strength. In addition to increasing the adhesive’s resistance to high temperatures, chemicals, water and UV light, cross-linked adhesives don’t undergo subsequent hardening after curing, so they have very stable, long-lasting properties of adhesion.
The improved cohesion of cross-linked adhesives also makes it possible to use higher adhesive coat-weights with less risk of bleeding. Higher coat-weights may be required particularly on rough or textured surfaces such as HDPE chemical drums and polymer or plastic powder-coated metal surfaces.

3.2.1. UV-cured and catalyst activated solutions

UPM Raflatac’s cross-linked adhesives are based on two technologies: UV-cured (UV-acrylic), and catalyst activated.

With UV acryls, photoinitiators in the adhesive start a cross-linking reaction when exposed to UV light. These radiation-cured adhesives are UPM Raflatac’s ‘RC’ adhesives. They enter the labelstock manufacturing process in solid form, are melted prior to coating onto the siliconized label liner, and passed under ultra-violet lighting.

Catalyst activated adhesives are UPM Raflatac’s ‘RX’ adhesives. They, too, enter the labelstock manufacturing process in solid form, and the cross-linking reaction is initiated by a catalyst after coating onto the label stock liner. The catalyst is simply water vapour. With the RX adhesives, UPM Raflatac has achieved an exceptionally high density of cross-links, producing our highest resistance to chemicals, UV light and shearing under high temperatures.

‘Shear’ is the measurement of an adhesive’s cohesion or internal strength. It is assessed according to FINAT test method 8, which measures the time it takes for the adhesive and label face to slide off a near-vertical, standard substrate. Adhesives with high shear values are typically more resistant to chemicals, oils, heat and long-term exposure to water.

3.2.2. Challenging conditions and their influence on adhesive selection

Labelling on durable goods underlines the importance of factors such as the conditions in which the label must perform and the life-expectancy of the label.

A smooth stainless steel surface on a piece of machinery, for example, should be relatively straightforward for adhesion because the substrate has high surface energy which encourages adhesive wet-out and bonding. However, a label for this kind of application may require very long-term resistance to heat, oils and chemicals as well as mechanical stress.

In the event of cohesive failure caused by such exposures, the adhesive layer would split apart (shear), leaving residue on the labelled substrate and on the label face material as the label face detaches.
Durable labelling is therefore an example of an end-use category where a cross-linked adhesive technology will likely be required, regardless of the substrate’s favourability to bonding in terms of surface energy. Naturally that adhesive formulation will also be adapted to the polarity of the substrate.

4. Identifying the right adhesive

In general, the lower the surface energy of the substrate, the more engineered and complex the adhesive needs to be to achieve reliable adhesion.

Labelling on ‘non-polar’ substrates demands a more complex formulation – but there also comes a point where a more sophisticated adhesive solution provides no extra benefits and becomes an inefficient choice. Water-based acrylic as well as hotmelt adhesives are modified to provide excellent properties of adhesion on a variety of polar and non-polar substrates in numerous end-uses.

There are, however, a variety of labelling areas where a still more engineered adhesive is required due to certain exposures the label needs to withstand. Sometimes this is in addition to issues with low surface energy, for example in some personal care end-uses, and sometimes this is regardless of surface energy as can be the case with durable labelling. These are instances where a UV-acrylic adhesive is most likely to provide the optimal solution.

UPM Raflatac can help you make the right choice of adhesive in a variety of ways. You can search for product and adhesive information at www.upmraflatac.com, where you can also browse or order technical information sheets and product brochures. You can also approach your UPM Raflatac contact, who will be pleased to help you identify the right choice of adhesive based on the details of the substrate being labelled and the conditions in which the label is expected to perform.