dataphysics

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Application note 14

Determination of the maximum work of adhesion of certain liquids

Task

Liquids (eg. inks, glues, or varnishes) perform work of adhesion to their solid base. In many cases, if we wish to maximise the adhesive force between a liquid and a certain solid substrate, it is necessary to know the optimum work of adhesion of our liquid on that chosen surface. In the given example, inks with different colour pigments (red, yellow and blue) are required to wet a foil (with as high as possible 'work of adhesion') in order to imprint the foil permanently.

In the case of this example. The surface free energy of the film is 40 mN/m, with a polar contribution of 10 mN/m. The inks have the following surface tensions (determined by measurements of the interfacial tensions in air and a second solvent, via the pendant drop method).

Red ink = 39,0 mN/m; polar 9,0 mN/m

Yellow ink = 44,0 mN/m; polar 9,0 mN/m

Blue ink = 40,5 mN/m; polar 9,5 mN/m

Method

The method follows the calculation according to Owens-Wendt-Rabel-Kälble (OWRK). (Symbols explained at end of text):

$$W_A = \sigma_l (1 + \cos\Theta) \qquad (1)$$

The work of adhesion according to OWRK is described by the following equation:

$$W_A = 2\left(\sqrt{\sigma_l^d \cdot \sigma_s^d} + \sqrt{\sigma_l^p \cdot \sigma_s^p}\right) \qquad (2)$$

The surface properties are divided into:

$$\sigma_l = \sigma_l^d + \sigma_l^p \qquad (3)$$

From (2) and (3) we get the work of adhesion:

$$W_A = \sqrt{(\sigma_l + \sigma_l^p) \cdot \sigma_s^d} + \sqrt{\sigma_l^p \cdot \sigma_s^p}$$

For certain surfaces, σ_s^p and σ_s^d are constant; for a constant work of adhesion, a function $\sigma_l(\sigma_l^p)$ for $\sigma_l^p \geq 0$

$$\sigma_l(\sigma_l^p) = \frac{\left(\frac{W_A}{2} - \sqrt{\sigma_s^p \cdot \sigma_l^p}\right)^2 + \sigma_s^d \cdot \sigma_l^p}{\sigma_s^d} \qquad (5)$$

This multi parameter equation can be used to provide the, so called, 'isograms' of work of adhesion of liquids (of a range of surface tensions vs. polar parts) in contact with a certain surface. Fig. 1 displays ten such isograms (like isobars on a weather map) corresponding to 'work' of 40 to 85 mN/m. Each work isogram includes a minimum, describing the lowest surface tension, for a defined degree of polarity that corresponds to that level of work. A liquid with these parameters (surface tension vs. polar part) will exert a maximum adhesive force on the given surface

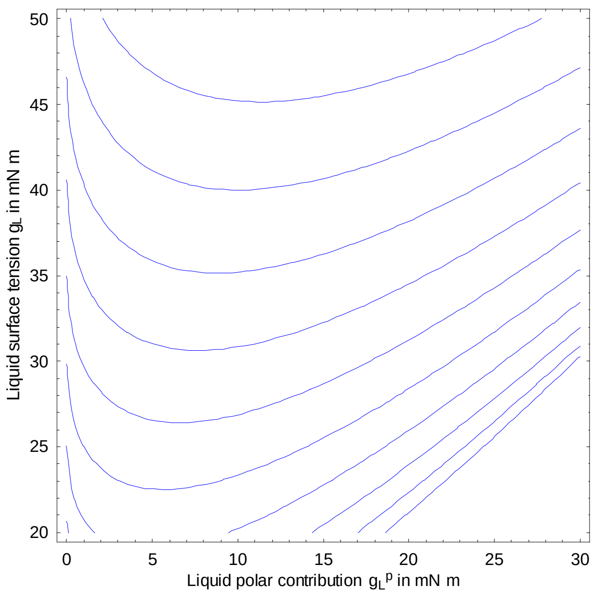

Abb. 1: Isolines fort he values given in the example

If in the derivative (5) is set = 0, the polarity of the minimum can be calculated. For $\sigma_l^p{}_{min}$ the following is valid:

$$\sigma^p_{l_{min}} = \left(\frac{W_A \sqrt{\sigma^p_s}}{2 \cdot (\sigma^p_s + \sigma^d_s)} \right)^2 \qquad (6)$$

For each level of the work of adhesion a value of the polarity (polar part of the total surface tension) can be identified (from the minimum in the isobar) and corresponding surface tension can be determined, the combination of which will provide for optimum adhesion. A straight line can be plotted through these 'minima' (optimum adhesive force for each level of work) and a range of acceptable performance (+/- % of optimum line) proposed. Fig. 2 includes a representation of this zone, within which the liquid adheres with an acceptable result.

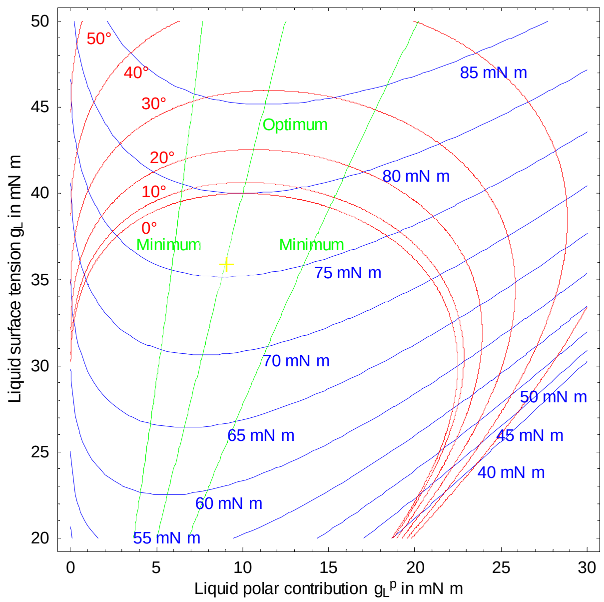

Abb 2: Diagram of the isograms (blue) of the adhesion work with the wetting envelope (red) and the corridor for optimum adhesion (green), as well as the values for the three sample inks.

Legend:

R: Red Ink

B: Blue Ink

Y: Yellow Ink

W_A = Work of Adhesion

σ_s = Surface free energy of the solid

σ_s^d = Surface free energy; dispersive contribution

σ_s^p = Surface free energy; polar contribution

σ_l = Surface tension liquid

σ_l^d = Surface tension; dispersive contribution

σ_l^p = Surface tension; polar contribution

θ = Contact angle

Result

The date represented in Fig. 2 shows that the blue ink (B) has good adhesive properties, being close to the optimum straight line. The blue ink also has excellent spreading behaviour (close to 0° on the wetting envelopes), due to it's low surface tension. The red ink is also close to the optimum adhesive force line, but as can be seen from it's high surface tension and position with ref. to the wetting envelopes (approx. 35°) it has limited spreading behaviour. The yellow ink will have a better tendency to spread than the red ink (lower surface tension and contact angle, as indicated by the wetting envelope) but bad adhesive properties (lies outside the acceptable zone) as a result of its relatively low polar part.

Summary

This method allows a unique opportunity to solve problems concerning adhesion of liquids on solids, in a quick and cost effective way. It provides an easy route to determine which combination of liquids and solids will adhere to the required degree. E.g. coating, printing and the fixing (gluing) of surfaces.

To optimise the work of adhesion there are two possibilities; on one hand the liquid could be modified in respect of its polar vs. disperse ratio. On the other hand it is possible to treat the solid surface, eg. by plasma treatment, to increase its polarity.