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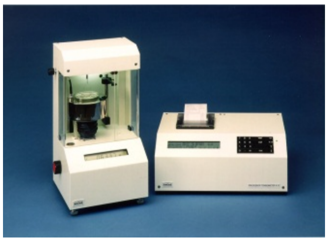
Application Report

Wetting and Adhesion of Hotmelts

Application report: AR223e
Industry section: Adhesives, chemical industry
Author: PR
Date: 2001


Drop Shape Analysis System DSA10


Force Tensiometer K12

Method:

Keywords: Hotmelts, adhesion, surface tension, surface free energy, elevated temperature

Wetting and Adhesion of Hotmelts – Optimization Using Surface Tension Measurement at High Temperature

In many industrial processes using adhesives the optimization of surface tension of the solids and liquids involved, plays a major roll for wetting and adhesion.

Hotmelts start to soften at about 100°C. Optimal application temperatures are between 110°C and 160°C depending on the composition of the hotmelt. At these temperatures the viscosity of hotmelts is low enough for optimal distribution of the glue on the surfaces to be pasted. To estimate the surface tension and the wettability of hotmelts the measurements have to be done at the application temperatures of the hotmelts.

In order to characterize the wetting both the contact angle of sessile drops and the surface tension of pendant drops for the hotmelts were measured by using a Drop Shape Analysis System DSA10, KRÜSS GmbH. In combination with the High Temperature Dosing System measurements were possible at the application temperature of hotmelts between 110°C and 170°C. From the measurement's results the disperse and polar part of the surface tension which represents an important criterion for the wettability of surfaces as well as the work of adhesion were calculated.

Contact Angle and Wetting

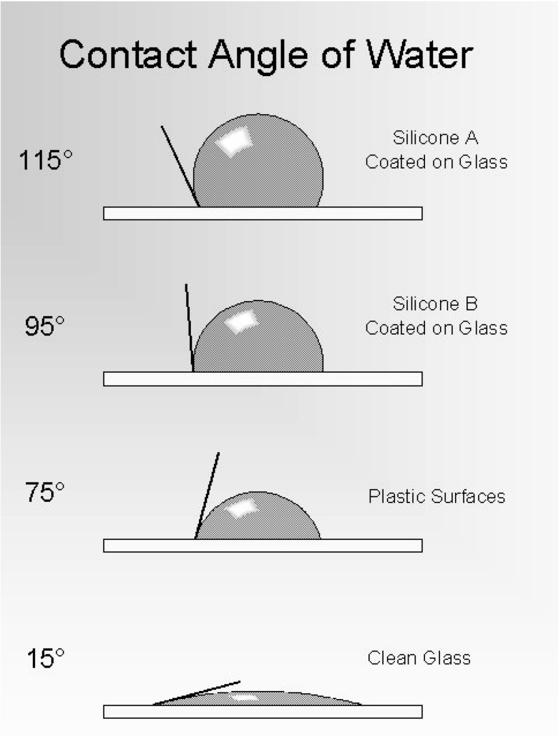


Fig. 1: Example for the formation of contact angles between water and different surfaces.

Wetting is understood as the formation of a new interface liquid/solid instead of the surface solid/gas.

In this case the solid corresponds to the solid surface to be pasted and the liquid to the hotmelt.

The contact angle θ indicates how the solid surface is wetted by the liquid. A contact angle of 0° means complete wettability: the liquid spreads out over the solid surface.

The larger the contact angle the worse is the wettability. In figure 1 an example for the formation of contact angles between water and different surfaces is shown. At contact angles θ < 90° the liquid wets the solid surface. At θ > 90° the surface is not wetted by the liquid.

For lim θ → 180° the work of adhesion between the solid and liquid is zero. But this limit is not reached in practice because disperse interactions occur in every kind of system.

Surface Tension of Liquids – Surface Free Energy of Solids

For the characterization of solid wettability by a liquid the knowledge of both the surface energy if the solid (in case of solids the term surface energy is generally used instead of surface tension) and the surface tension of the liquid is essential.

However, two solids having a similar surface energy can display different wettability against the same liquid. In order to explain this phenomenon one have to have a closer look at the terms “surface tension” and “surface free energy”.

The total surface tension consists of the disperse part σ^D and the polar part σ^P:

$$\sigma = \sigma^D + \sigma^P \qquad (1).$$

The disperse part σ^D consists of:

- Van der Waals interactions

and the polar part σ^P consists of:

- dipol-dipol interactions
- hydrogen bonds
- Lewis acid/base interactions
- charge-transfer interactions

Despite of similar surface tensions the ratio between the disperse and the polar part can be very different. Only parts of the same origin contribute to the interaction between solid and liquid and are important for the estimation of the wettability. In case one phase is apolar, i.e. $\sigma^P = 0$ only disperse interactions will occur.

Work of Adhesion

The work of adhesion characterizes the actual strength of adhesion between two surfaces. Is the polar and disperse part of the surface tension (surface free energy) given, the work of adhesion W_{12}^a is calculated according to the theory of Dupré (Eq. 2):

$$\Delta G^a = \sigma_{12} - \sigma_1 - \sigma_2 = -2[(\sigma_1^D * \sigma_2^D)^{1/2} + (\sigma_1^P * \sigma_2^P)^{1/2}] = -W_{12}^a \qquad (2).$$

The larger the work of adhesion W_{12}^a the stronger is the adhesion between these two phases.

The values for a certain liquid can now be combined with σ^D and σ^P of different solids. From the results the optimal properties of the solid surface for a maximum adhesion can be derived.

Surface Tension Measurements of Hotmelts (Pendant Drop Method)

The measurements of the surface tension were carried out by using a Drop Shape Analysis System DSA10, KRÜSS GmbH in combination with the High Temperature Dosing System.

Two commercial hotmelts for hotmelt glue guns and three industrial hotmelts used as glues for diapers were tested. In table 1 the tested samples and the sample designations are summarized.

Sample designation	Characterization
Sample P	commercial hotmelt
Sample U	commercial hotmelt for low temperature applications
Sample 1	industrial hotmelt
Sample 2	industrial hotmelt
Sample 3	industrial hotmelt

Table 1: Tested hotmelts and their sample designations

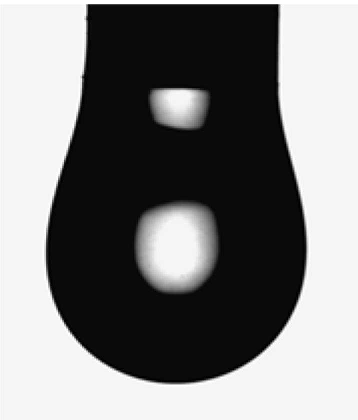


Fig. 2: Video frame of a pendant drop, Sample U, 110°C

By using the method of Pendant Drop (fig. 2) the surface tension of hotmelts were estimated in dependence on drop age and on temperature in the range from 110°C and 170°C, depending on the current hotmelt composition.

The drop was recorded by a video camera and the drop shape was analyzed by the software DSA1, KRÜSS GmbH using the Young-Laplace equation. In result the surface tension was obtained. The results are summarized in table 2.

Sample	Tempe-rature [°C]	Surface tension σ [mN/m]	Contact angle θ [°]	Disperse part σ^D [mN/m]	Polar part σ^P [mN/m]
Sample P	120	44,31	58,9	44,31	0
Sample U	120	43,81	54,3	54,3	0
Sample 1	120	28,94	49,6	28,44	0,5
	130	27,79	47,3	27,79	0,31
	140	27,13	46,8	26,11	1,02
	150	25,92	47,3	23,65	2,27
	160	25,19	48,4	21,96	3,23
Sample 2	120	24,20	55,6	17,93	6,27
	130	23,26	54,8	16,80	6,45
	140	22,62	56,5	15,40	7,22
	150	21,94	56,8	14,41	7,53
	160	20,75	57,4	12,74	8,00
Sample 3	130	27,81	60,6	21,49	6,32
	140	26,04	60,7	18,78	7,24
	150	24,76	61,0	16,90	7,86

Table 2: Surface characteristics of hotmelts

The commercial hotmelts showed a higher surface tension in comparison to the industrial hotmelts. The industrial hotmelts (sample 1 to 3) have a significant temperature dependence. With increasing temperature the surface tension decreases (Tab. 2).

The surface tension was also measured in dependence on time (Fig. 3). Clear differences in the dependence of the surface tension on the drop age were registered. In opposite to sample 1 and 3 sample 2 showed a constant surface tension with increasing drop age.

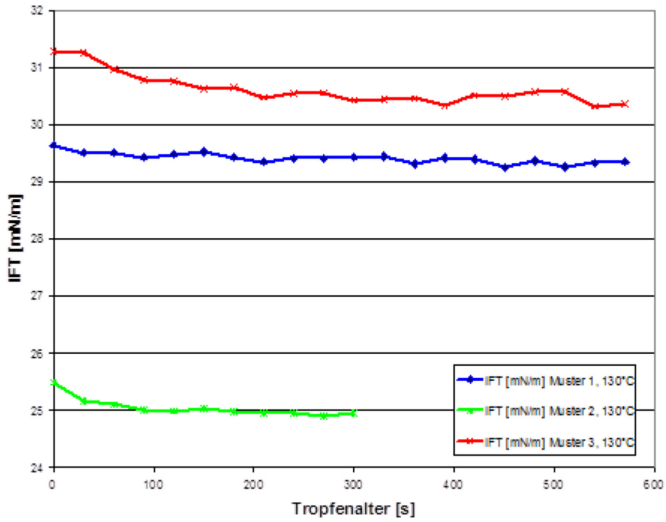


Fig. 3: Dependence of the surface tension on the drop age for sample 1 to 3 at 130°C

Contact Angle Measurements of hotmelts on PTFE (Sessile Drop Method)

The used equipment and tested samples were the same as for the measurements in the previous chapter. Using the High Temperature Dosing System a drop was given on PTFE and the right and left contact angle was estimated. To fit the drop shape the Tangent 1- and Tangent 2-Method was chosen in the software DSA1.

In table 2, column 4 the estimated contact angles are summarized. All contact angles are smaller than 90°, especially sample 2 showed low contact angles and good wettability on PTFE.

Fig. 4: Contact angle measurements of a sessile drop, sample U, 130°

Using the surface tension and contact angle on PTFE the disperse part can be calculated for each sample in dependence on temperature (Eq. 3[1]):

$$\sigma_l^d = \frac{\sigma_l^2}{4\sigma_s}(1+\cos\theta)^2 \qquad (3)$$

where σ_l^d is the disperse part of the liquid (hotmelt), σ_l the surface tension of the liquid, σ_s the surface tension of the apolar solid (PTFE) and θ the contact angle of the liquid on the apolar solid. The polar part results from the difference of the total surface tension minus the disperse part.

In table 2 the polar and disperse part of the surface tension for different hotmelts are summarized.

Samples P, U and 1 have only small polar parts, whereas for sample 2 and 3 the polar parts are significantly higher.

Calculation of the Work of Adhesion

From the polar and disperse part of the surface tension of hotmelts the work of adhesion for different solid surfaces can be calculated, provided that the polar and disperse parts of the solids are known. Exemplary the work of adhesion was calculated for sample 1 at 140°C in combination with different solid surfaces which are often used in practice (table 3).

The values of the work of adhesion are particularly high for glass, PMMA and PET. All these substances display a large disperse part of the surface tension which can interact with the disperse part of the hotmelt. The higher the work of adhesion the stronger is the adhesion of the hotmelt on the solid surface.

Combination hotmelt/solid	Work of adhesion [mJ/m^2]
Sample 1 / ABS	66,15
Sample 1 / alumina	54,72
Sample 1 / glass	73,89
Sample 1 / iron oxide on iron	52,96
Sample 1 / PA6.6	64,59
Sample 1 / PC	64,87
Sample 1 / PE-LD	57,90
Sample 1 / PE-HD	60,55
Sample 1 / PET	66,61
Sample 1 / PMMA	69,17
Sample 1 / PP	58,13
Sample 1 / PS	66,30
Sample 1 / PVC	64,30
Sample 1 / PTFE	46,52
Sample 1 / PVC	64,30
Sample 1 / steel	57,95

Table 3: The work of adhesion for different combinations of sample 1 at 140°C/solid surfaces

Summary

The surface tension as well as the contact angle on PTFE of different hotmelts were estimated using the Drop Shape Analysis System in combination with the High Temperature Dosing System. It could be shown, how the disperse and the polar part of the surface tension and the work of adhesion are calculated and to which extent these are relevant for the estimation of the wettability of solids.

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