Application Report

Effect of Temperature on the Surface Energy of Solids

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Method:

Force Tensiometer – K100

Drop Shape Analyzer – DSA100

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Effect of Temperature on the Surface Energy of Solids – Sometimes It Does Matter

(Probe Liquid Recommendations)

Abstract

Surface energy values are rarely measured for solids at elevated temperatures. Even when the goal is understanding spreading and/or adhesion between a molten material (such as a hot melt adhesive) and a solid surface, most commonly surface energy values for the solid surface are assumed to be those measurable at room temperature. Here we suggest that such an approach can be problematic particularly when you have finish coatings on metals or the remnants of drawing and stamping lubricants, which is quite common for metals. So, we share a probe liquid set (with characterization) which can be used for high temperature solid surface energy in two-components up to 200°C.

Method

The Krüss Drop Shape Analyzer – DSA100 is used along with an elevated temperature chamber to measure the surface energies of chrome plated steel and aluminum foil at 40°C and 160° by the Fowkes method using contact angles obtained by the sessile drop method. For purposes of making such measurements, at atmospheric pressure, high boiling point contact angle probe liquids are necessary and must be previously characterized. We used the Fowkes method to characterize 1- bromonaphthalene and ethylene carbonate (1,3 dioxlan-2-one) for surface tension with polar and dispersive components at a variety of temperatures. Overall surface tensions were measured using a Krüss Force Tensiometer – K100 and separated into components by testing for contact angle against poly(tetrafluoroethylene) (PTFE). The liquids were then put to use at 40°C and 160° to characterize the chrome plated and aluminum surfaces. Both liquids have boiling points above 240°C.

Experiment

Based on plate method surface tension measurements with a Force Tensiometer – K100 and sessile drop contact measurements for the liquids on PTFE the following surface energy characterizations were made for the two probe liquids of interest by Fowkes method.

Temperature °C	1-bromonaphthalene Overall Surface Tension (mN/m)	1-bromonaphthalene Surface Polarity (%)
40	43.93	1.07
60	43.00	1.44
80	42.14	1.78
100	41.34	2.09
120	40.59	2.39
140	39.88	2.67
160	39.22	2.94
180	38.60	3.18
200	38.02	3.42

Table 1: Surface Tension Data – 1-bromonaphthalene

Temperature °C	ethylene carbonate Overall Surface Tension (mN/m)	ethylene carbonate Surface Polarity (%)
40	53.74	63.41
60	51.92	60.99
80	50.32	58.98
100	48.84	57.22
120	47.50	55.68
140	46.27	54.34
160	45.14	53.16
180	44.11	52.13
200	43.16	51.23

Table 2: Surface Tension Data – ethylene carbonate

The following contact angles were measured and surface energies determined for the surfaces at the two temperatures of interest.

Sample	Chrome Plated Steel	Chrome Plated Steel
Temperature	**40°C**	**160°C**
Contact Angle with 1-bromonaphthalene	54.7°	41.4°
Contact Angle with Ethylene Carbonate	42.2°	22.6°
Overall Surface Energy (mJ/m²)	**42.16**	**42.02**
Polar Component (mJ/m²)	**19.01**	**18.91**
Dispersive Component (mJ/m²)	**23.15**	**23.11**
Surface Polarity (%)	**45.11**	**45.01**

Table 3: Chrome Plated Steel – Surface Energy Data

Sample	Aluminum Foil	Aluminum Foil
Temperature	**40°C**	**160°C**
Contact Angle with 1-bromonaphthalene	44.1°	35.2°
Contact Angle with Ethylene Carbonate	39.0°	38.2°
Overall Surface Energy (mJ/m²)	**45.31**	**38.21**
Polar Component (mJ/m²)	**17.30**	**11.25**
Dispersive Component (mJ/m²)	**28.01**	**26.96**
Surface Polarity (%)	**38.19**	**29.44**

Table 4: Aluminum Foil – Surface Energy Data

Results

The chrome plated steel was of interest for surface energy analysis at high temperature because it forms the die head for a polymer extrusion process, and it was desired to have molten polymer adhesion to be as low as possible. The aluminum foil sample was of interest for surface energy because it is to be bonded with molten polymer (hot melt) to another polymer film in our customer's process to make holographic film.

The findings were that the chrome plated steel had very similar surface energy values at 40°C and 160°C.

(42.16 mJ/m^2 with 45.11% surface polarity at 40°C)
(42.02 mJ/m^2 with 45.01% surface polarity at 160°C)

The foil sample on the other hand, decreased substantially in terms of overall surface energy and surface polarity at 160°C versus at 40°C.

(45.31 mJ/m^2 with 38.19% surface polarity at 40°C)
(38.21 mJ/m^2 with 29.64% surface polarity at 160°C)

It is sometimes valid to use solid surface energy data at room temperature as a legitimate estimation of the surface energy of the same solid at elevated temperature (as with the chrome plated steel above). However, other times it is not. In the case of metals this may be due to surface oxidation changes, rearrangement of a surface coating, or other aspects not necessary completely understood. We have also seen the effect in sputter coated surfaces such as gold, nickel, etc. In the case of polymers passing glass transition temperatures and secondary transition temperatures, well before the melt point, can also change surface energy substantially. These changes may well be important to the complete understanding of your adhesion and wetting processes. Please feel free to use the probe liquids and data above in your elevated temperature surface energy evaluations, or to contact us if you wish to have such measurements made on your systems.

Summary

Surface energies of solids are most commonly only measured at room temperature and assumed to be similar at elevated temperatures for most adhesion energy work. However, it is often the case that substantial differences exist with temperature in the surface energies of real surfaces including metals that may contain surface coatings effected by temperature and polymers. In this note we offer the surface tension components for two surface energy probe liquids 1-bromonaphthalene and ethylene carbonate (1,3 dioxlan-2-one) which can be used, along with sessile drop contact angle measurements to determine the surface energy of solids up to 200°C. The example data are for chrome plated steel (of interest for a die application) and an aluminum foil (of interest for the formation of holographic film). We find the chrome plated steel to have similar surface energy at 40°C and 160°C. The aluminum foil, however, is found to decrease in surface energy by about 7 mJ/m^2 and in surface polarity by about 7% over the same temperature range.

Literature

[1] “So you Want to Measure Surface Energy?” KRÜSS technical note TN306e
(available for download at www.kruss-scientific.com)

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