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Monitoring of paint adhesion on polymers using photothermal detection

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Abstract

Photothermal detection allows for remote and non destructive inspection of near-surface areas. The physical mechanism involved is reflection of thermal waves at discontinuities. Based on theoretical models we investigate the kind of paint/polymer boundary and correlate it to surface preparation and to the resulting adhesion.

1. Photothermal boundary inspection

Characterisation of adhesion of paint on polymer substrates has considerable relevance for applications. Besides destructive tests there is increasing research interest in non destructive inspection. It is obvious that the adhesion of a layer on a substrate should be correlated with the boundary situation between the two media. That is why photothermal characterisation of the boundary is of interest [1]. For such an inspection one uses an intensity modulated light beam which generates a temperature modulation propagating as a *thermal wave* from the surface into the interior of the sample. The quantity of interest for this process is the thermal impedance Z depending on effusivity and modulation frequency. Local discontinuities of Z (*impedance mismatch*) cause reflections that affect the resulting surface temperature modulation which is monitored e.g. by photothermal radiometry [2].

Though paint and polymers are very similar materials, their small thermal mismatch allows for boundary inspection using thermal waves in such a way that conclusions can be made concerning the existence of a contact resistance or a smeared transition (*figures 1 and 2*).

The thermal contact resistance is an indicator for starting loss of bonding or delamination of coatings [3,4]. A suitable model is the development of a thin air gap combined with multiple solid-solid contact areas. Results of calculations for various values of contact resistance are shown in *figure 1*. The opposite behaviour is shown by curves calculated for a boundary that displays a gradual transition between the two values of Z (*figure 2*) [5]. This is the situation for interdiffusion or chemisorption.

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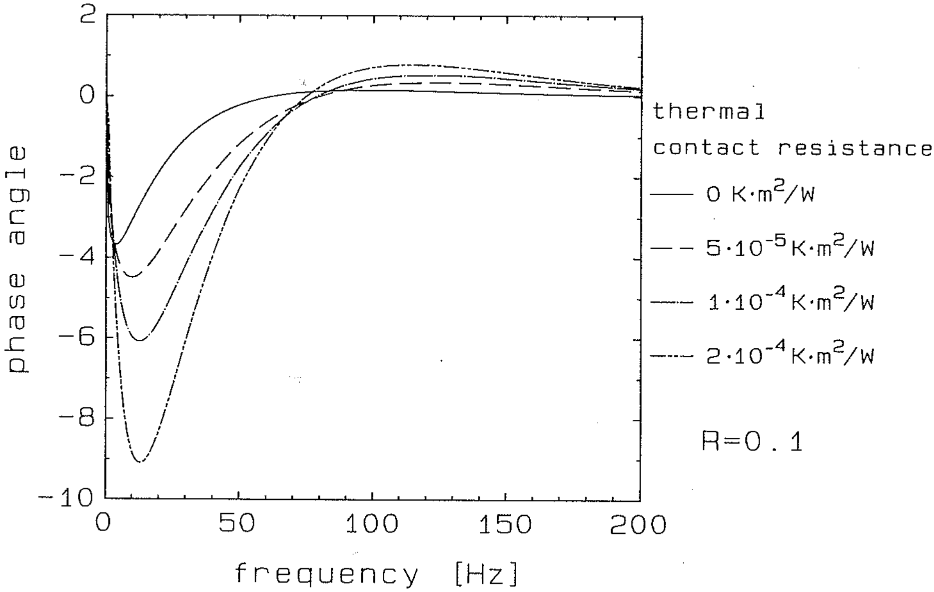

Fig. 1. - Effect of contact resistance on phase/frequency curve. The curves were calculated for thermal reflection coefficient 0.1 and a layer thickness of 40 μm.

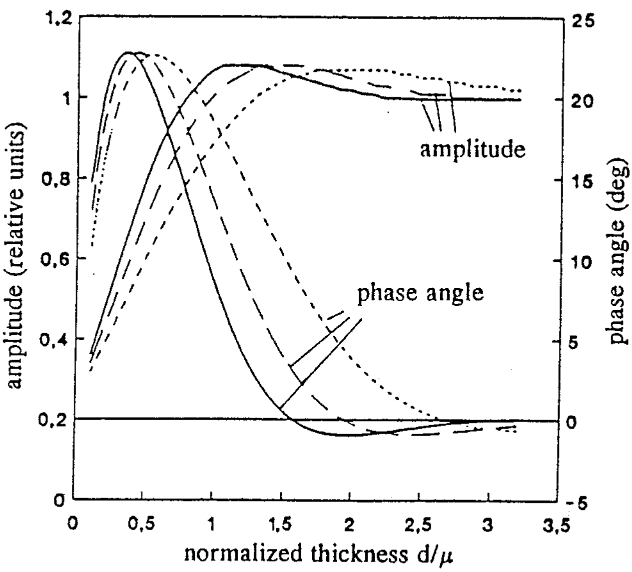

Fig. 2. - Theoretical amplitude and phase angle curves for smeared transitions. Different line types indicate different gradients of thermal properties.

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A comparison between one dimensional model calculations and experimental data requires phase angle accuracy of about 0.1 degree and a broad laser beam that allows to neglect lateral heat flow. Furthermore we assume that absorption of light and emission of thermal infrared radiation occur only in the paint surface. As the theoretical treatment becomes very complicated if these simplifying assumptions are no longer valid, one should be careful to provide the appropriate experimental conditions.

2. Experimental results

Figure 1 shows that for a given thickness of the layer there exists a modulation frequency where the contact resistance has its strongest effect. Consequently it is reasonable to use this frequency that provides the highest sensitivity. Results indicate that in this case the effect of pretreatment is stronger than the variation of data (caused by statistical fluctuations of the paint thickness) obtained for various samples (*figure 3*).

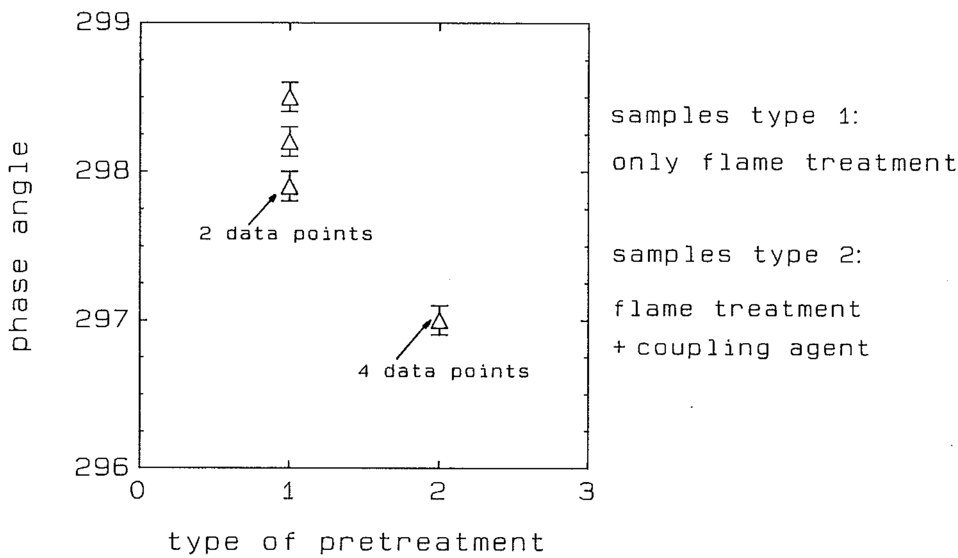

Fig. 3. - Comparison between coated samples with different surface pretreatment of the substrate. Four samples were investigated for every type of pretreatment.

The effect of a smeared transition is indicated by the measured phase/frequency-curves (*figure 4*) for paint on metal where variations in the kind of transition were obtained by suitable pretreatment. In agreement with *figure 2* smeared transitions shift the zero crossing point to higher frequencies.

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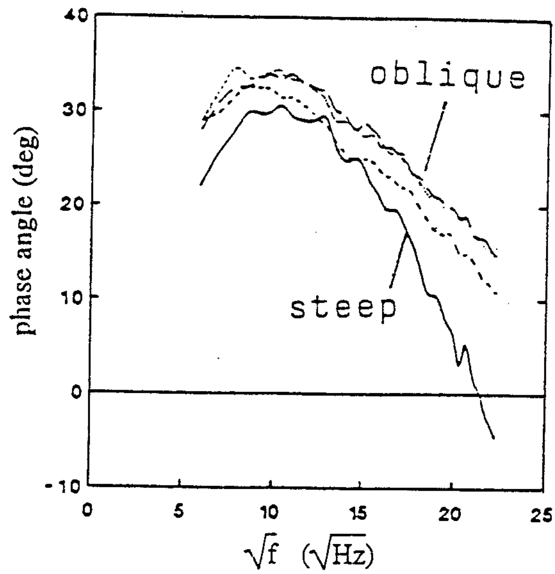

Fig. 4. - Photoacoustic measurement of phase angle for paint on copper. Thick line: no interface layer; broken lines: with different interface layers

3. Conclusion

The thermal wave reflection coefficient of boundaries between very similar materials like paint and polymers may be very small. However there is strong indication that the kind of transition (smeared or discontinuous) affects data well enough to be revealed from them. On this background we expect that thermal waves are applicable to characterise the quality of surface pretreatment to improve adhesion.

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