

ROLE OF SURFACE ROUGHNESS OF THE ADHERENT SURFACE ON THE DEBONDING MECHANISMS OF PSA

Arnaud Chiche and Costantino Creton

Laboratoire PCSM, ESPCI
10, rue Vauquelin
75231 Paris Cedex 05 - France
email : arnaud.chiche@espci.fr

INTRODUCTION

Probe tack is the optimal technique to study adhesion properties of soft polymers for short contact time conditions. This technique consists in the formation and separation of a bond between a thin polymer layer and a hard flat surface.

Previous studies noted differences in adhesion energy between tests performed with the same adhesive on smooth and rough surfaces. They were interpreted as an effect due to the roughness on the debonding micromechanisms [1, 2]. However, these studies were limited to a binary system (smooth or rough) and had a limited control of the tested adherent surfaces. Therefore they were not able to identify how the adhesion micromechanisms were precisely affected by the adherent's roughness.

In order to investigate this aspect in more detail, we designed better controlled probe surfaces having different roughnesses, and characterized them with an optical profilometer. We also took advantage of our custom designed probe tack apparatus [2], which allows the simultaneous acquisition of a nominal stress and strain curve and the observation of the adhesive film from underneath the transparent substrate. Our study was done on 100 μm poly(2-ethylhexyl acrylate) (PEHA) latex films, and only the surface topography of our stainless steel probe was changed. We worked all the time with the same experimental conditions, i.e. 1 MPa contact pressure, 1 s contact time, and 30 $\mu\text{m/s}$ debonding rate.

SURFACE PREPARATION

To change the surface roughness of the probe, we polished them to different degrees, with abrasive plates of decreasing grain size. Moreover, we polished the samples near the edge of the disc, in a constant direction, in order to have a non isotropic surface made of quasi-periodic grooves.

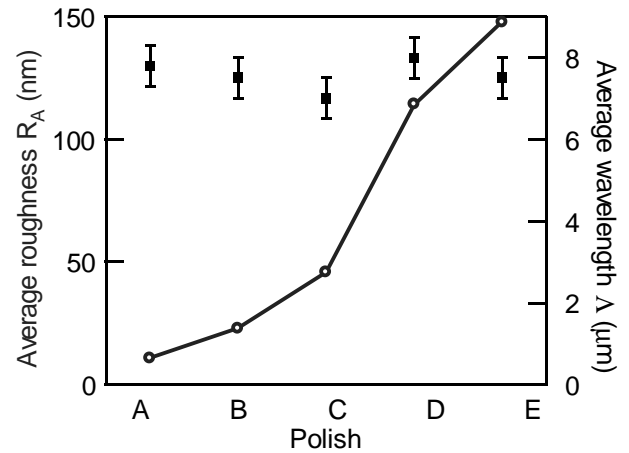


Figure 1 : features of the probe surfaces we used in this study, i.e. average roughness R_A and the grooves wavelength Λ .

The samples were characterized using an optical profilometer to map out the surface. This technique allowed us to measure the surface average roughness and wavelength, as observed from figure 1. The roughness R_A increased from 11 nm to 148 nm while the wavelength Λ was constant at about 7.6 μm .

RESULTS

We performed three or four tests for each of the five tested probes to improve the statistics. Then, we were able to select for each case representative stress versus strain curves, which are reported on figure 2. All the tests performed were recorded, and representative images of the debonding are shown on figures 4 and 5. Both mechanical and video data show a dual effect of increasing the adherent's roughness on the debonding micromechanisms in the case of our model adhesive: first an enhancement of the cavitation process, then a decrease in the process of expansion and coalescence of the cavities.

EFFECT ON THE CAVITATION PROCESS

If we consider the first stage of the tests (left part of figure 2), we note a progressive decrease of the measured σ_{max} with increasing amplitude of surface roughness (also shown on figure 3), which means that cavities appear at lower levels of stress for the rougher surfaces. Topological defects favor cavitation, acting presumably as nucleation sites. Note also the decrease in the size of error bars in figure 3 which is associated with a better reproducibility of the results on rough surfaces. Smooth surfaces have less defects and are more sensitive to a single large defect.

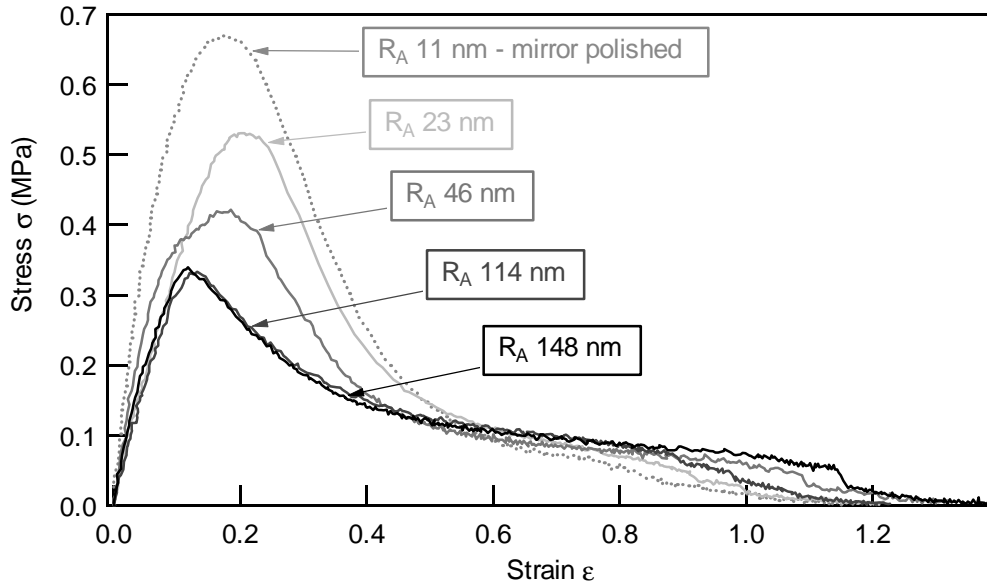


Figure 2 : Representative stress vs strain curves of a PEHA latex on the rough stainless steel surfaces. Test conditions are: room temperature, 1 MPa of contact pressure, short contact time (1s), and moderate debonding velocity (30 $\mu\text{m/s}$).

The role played by surface defects in nucleating cavities is at this stage not fully clear. It may create local stress inhomogeneities (contact time is expected to have an influence), or facilitate air trapping processes [3] inducing a “suction-cup” effect [4], although we did not see such phenomena in our tests. Furthermore, it is interesting to note that the period of the grooves is identical for all probes and much smaller than the observed distance between cavities. The distance between defects may be controlled by the elastic properties and the thickness of the layer more than by the distribution of defects [5]. However the level of stress at which a surface defect is able to nucleate a cavity in the adhesive clearly depends on its size.

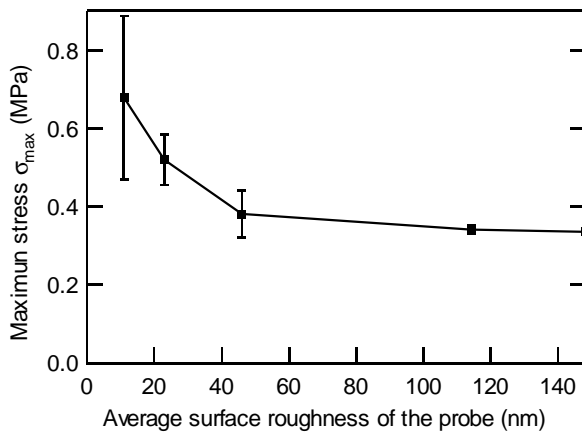


Figure 3 : Maximum stress of the debonding curves. We can also note that σ_{max} becomes independent of surface roughness at high amplitudes (more than 100 nm).

This could be associated either with a larger size or with a larger density of defects, according to recent theoretical investigations of Ioulia Chikina, Cyprien Gay [5] and Gwendal Josse about stress relaxed zone around bubbles.

EFFECT ON THE CAVITIES EXPANSION

The next interesting point is what happened after cavities appeared. On figure 2, the slope of the stress versus strain curve just after the maximum stress decrease with increasing roughness, which is a typical sign of a decreasing lateral propagation rate of the cavities. Indeed, a faster lateral expansion of the cavities on the smooth surface is apparent on figure 4. As soon as the cavities appear, they present a distinct non-spherical shape on the smoothest surface while they remain spherical on the rough ones. This implies [6] a less dissipative propagation of the debonding front at the probe/film interface for the smooth probe.

Moreover, figure 5 shows that inter-cavity walls, which become thinner as the debonding process continues, remain distinctly wider on rough than on smooth surfaces. The coalescence time between adjoining cavities increases, so fibrils can be more easily formed on rough surfaces than on smooth ones, which gives a higher and more regular plateau and increases the maximal strain as seen in figure 2. This decrease in propagation velocity can be due to different processes [7] which are unfortunately not easy to separate.

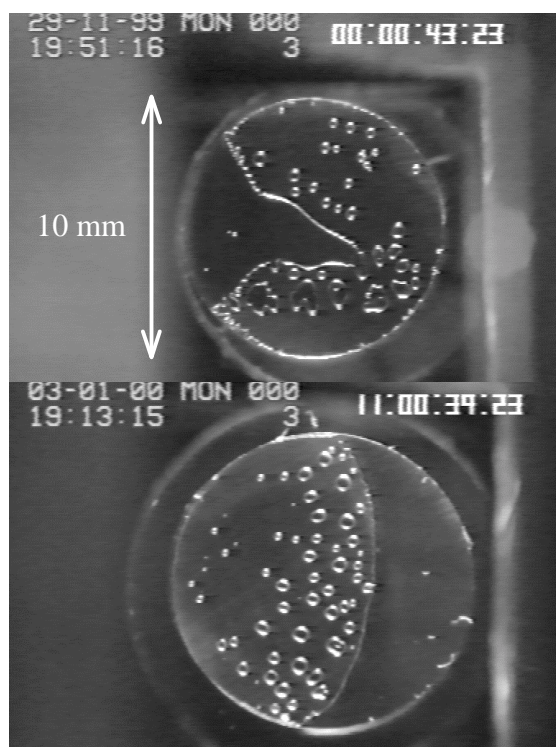


Figure 4 : Images taken at the time of maximum stress during the debonding from the smoothest surface (top) and the roughest one (bottom).

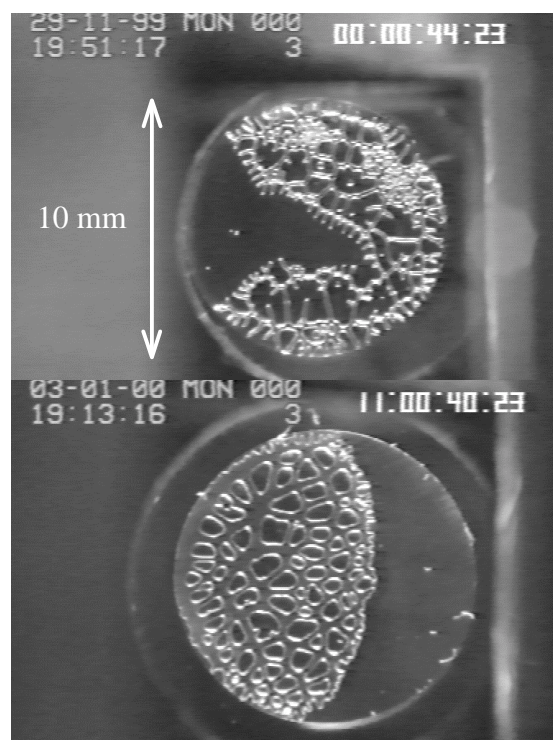


Figure 5 : Images taken at the beginning of the plateau, precisely one second after the maximum stress during debonding from the smoothest surface (top) and the roughest one (bottom).

CONCLUSION

This work is a preliminary study which allowed us to shed some light on the role of surface roughness on the debonding micromechanisms. First, roughness introduces surface defects that favor cavitation by creating local stress inhomogeneities or by air trapping processes. This effect seems to saturate at high roughness, a result which we cannot still correlate with certainty to the size of the defects or to their density.

Secondly, we find a significant decrease in the lateral expansion rate of cavities with increasing surface roughness. This leads to an increase in the final cavity size and slows down the coalescence between adjacent cavities resulting in an increase in fibril stability. The rate of lateral expansion is controlled by the dissipative processes at the edge of the cavity. Presumably, the surface topography controls this dissipation, in an analogous way to the dynamic wetting process on rough surfaces, even if the cavitation effect may have influence on the crack propagation.

REFERENCES

1. A. Zosel, *J. Adhesion Sci. Technol.* **11**, 1447 (1997)
2. H. Lakrout, P. Sergot, and C. Creton, *J. Adhesion* **69**, 307 (1999)
3. C. Creton and L. Leibler, *J. Polym. Sci.: part B : Polymer Physics* **34**, 545 (1996)
4. C. Gay and L. Leibler, *Phys. Rev. Lett.* **82**, 936 (1999)
5. I. Chikina and C. Gay, *Phys. Rev. Lett.* **85**, 4546 (2000)
6. C. Creton and H. Lakrout, *J. Polym. Sci.: part B : Polymer Physics* **38**, 965 (2000)
7. A. Chiche, P. Pareige, and C. Creton, *C. R. Acad. Sci. Paris, t.1, série IV* **9**, 1197 (2000)