Electronic Supplementary Material (ESI) for RSC Advances.

Characterization and Failure Modes Analyses of Air Plasma Oxidized PDMS-PDMS Bonding by Peel Testing

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Supplementary Information

There were 13 different combinations of the plasma treatment parameters tested, as seen in Table 1 below. Of the 69 samples tested (three samples tested for each combination), there is 1 outlier that was associated with the treatment condition 200 mTorr in pressure, 6.8W in power, and 50 s in treatment time. Our results reported in this manuscript has excluded this outlier.

Table 1 Experimental data.

Pressure (mTorr)	Power (W)	Treatment Time (s)	Max. load (N/mm)	Failure mode	Pressure (mTorr)	Power (W)	Treatment Time (s)	Max. load (N/mm)	Failure mode
200	6.8	40	0.045	peeling	300	6.8	30	0.155	tearing
200	6.8	40	0.0358	peeling	300	6.8	40	0.132	tearing
200	6.8	40	0.0263	peeling	300	6.8	40	0.132	tearing
200	6.8	50	0.208	tearing	300	6.8	40	0.14	tearing
200	6.8	50	0.168	tearing	300	6.8	50	0.111	tearing
200	6.8	60	0.186	tearing	300	6.8	50	0.132	tearing
200	6.8	60	0.184	tearing	300	6.8	50	0.14	tearing
200	6.8	60	0.174	tearing	300	6.8	60	0.129	tearing
200	10.5	30	0.04	peeling	300	6.8	60	0.147	tearing
200	10.5	30	0.17	tearing	300	6.8	60	0.179	tearing
200	10.5	30	0.198	tearing	300	10.5	30	0.074	peeling
200	10.5	40	0.195	tearing	300	10.5	30	0.153	tearing
200	10.5	40	0.06	peeling	300	10.5	30	0.09	mixed
200	10.5	40	0.155	tearing	300	10.5	40	0.09	peeling
200	10.5	50	0.06	peeling	300	10.5	40	0.182	tearing
200	10.5	50	0.201	tearing	300	10.5	40	0.182	tearing
200	10.5	50	0.22	tearing	300	10.5	50	0.118	tearing
200	10.5	60	0.217	tearing	300	10.5	50	0.14	tearing
200	10.5	60	0.227	tearing	300	10.5	50	0.142	tearing
200	10.5	60	0.06	peeling	300	10.5	60	0.147	tearing
200	18	30	0.07	peeling	300	10.5	60	0.132	peeling
200	18	30	0.142	tearing	300	10.5	60	0.163	tearing
200	18	30	0.203	tearing	300	18	30	0.158	tearing
200	18	40	0.231	tearing	300	18	30	0.053	mixed
200	18	40	0.11	peeling	300	18	30	0.161	tearing
200	18	40	0.231	tearing	300	18	40	0.155	tearing
200	18	50	0.15	tearing	300	18	40	0.082	tearing
200	18	50	0.269	tearing	300	18	40	0.161	tearing
200	18	50	0.166	tearing	300	18	50	0.121	tearing
200	18	60	0.229	tearing	300	18	50	0.216	tearing
200	18	60	0.205	tearing	300	18	50	0.147	tearing

200	18	60	0.085	mixed	300	18	60	0.192	tearing
300	6.8	30	0.153	tearing	300	18	60	0.169	tearing
300	6.8	30	0.134	mixed	300	18	60	0.205	tearing

Based on Kendall's work,[1] below we present a revised energy balance equation to describe peeling of two elastic thin films from each other. Consider two elastic thin films bonded as shown in Figure 1. The peeling force *F* is applied to progressively separate the bonding. For our peel testing, *F* is the maximum load at which the bonded PDMS strips begins to separate. Kendall's equation is based on the conservation of energy under a quasi-static loading condition in de-bonding the specimen over a length Δc:

$$U_p + U_A + U_E = 0 \tag{1}$$

where U_p is the potential change due to work done on the specimen, U_S is the adhesive energy released during de-bonding, and U_E is a change elastic strain energy of the specimen. Each energy term is described below.

U_p is obtained by multiplying the peeling force *F* by its movement in the direction of *F* for each strip of the bonded assembly. Let θ be the angle between the tangent to the bonding interface and the direction of the peeling force. Per the sketch in Figure 2, the net displacement of point A in the direction of the peeling force *F* after over a length Δc of de-bonding is $\Delta c(1 - \cos\theta)$. (It can be calculated by projecting the segment $\bar{A}A'$ onto the direction of *F*.) Therefore, U_p is equal to $2F\Delta c(1 - \cos\theta)$. This value is twice as large as formulated by Kendall because two elastic thin-film strips are considered, as oppose to Kendall's formulation for one elastic strip peeled from a solid substrate.

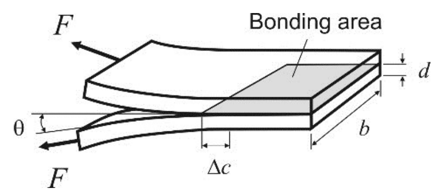

Figure 1. Peeling of two elastic thin films.

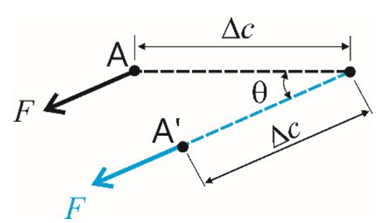

Figure 2. Configuration of the displacement of the de-bonded surface. The configuration of a length Δc before de-bonding (in black) and after de-bonding (in blue).

U_A is the adhesive energy released from the de-bonded surface and equal to $-Rb\Delta c$, where R is the adhesive energy per unit area.

U_E is the strain energy stored in the system and equal to $\frac{F^2\Delta c}{Ebd}$, where *E* is the Young's modulus of the thin film.

Per Eq. (1), the conservation of potential energy leads to:

$$-Rb\Delta c + 2F\Delta c(1 - \cos\theta) + \frac{F^2\Delta c}{Ebd} = 0 \quad (2)$$

Equation (2) can be further simplified. Per Kendall's argument, for soft materials like PDMS, the strain energy U_E can be neglected (because the stress $\frac{F}{bd}$ is much smaller than the Young's modulus *E*). It leads to

$$R = 2\frac{F}{b}(1 - \cos\theta) \quad (3)$$

where F/b is the maximum load per unit width of each thin-film strip.

References

1. K. Kendall, *Journal of Physics D: Applied Physics*, 1975, **8**, 1449.