Electronic Supplementary Material (ESI) for RSC Advances.

Supplementary Information

Self-folding of Polymer Sheets Using Microwaves and Graphene Ink

Duncan Davis[1], Russell Mailen[2], Jan Genzer*[1], Michael D. Dickey,*[1]

[1] Department of Chemical and Biomolecular Engineering, NC State University
[2] Department of Mechanical and Aerospace Engineering, NC State University

Approximating the temporal evolution of temperature

The temperature in the heating profiles can be approximated by the *tanh* function:

$$T(t)=\frac{c}{2}\left[\tanh\left(a\left(t-t_0\right)\right)+1\right]+T_0 \tag{S1}$$

where a, t_0, c, and T_0 are adjustable parameters. The parameters a and c help define the heating rate (*i.e.*, dT/dt) and t_0 represents the time corresponding to the inflection point in the T=T(t) curve. Using the expression in Equation (S1), one can calculate the heating rate as:

$$\frac{\partial T(t)}{\partial t}=\frac{c}{2}\frac{\partial T(t)}{\partial t}\left[\tanh\left(a\left(t-b\right)t_0\right)+1\right]=$$

$$=\frac{c}{2}\frac{4a}{\left[e^{a\left(t-t_0\right)}+e^{a\left(b-t_0\right)}\right]^2}=\frac{2ac}{\left[e^{a\left(t_0-b\right)}+e^{a\left(b-t_0\right)}\right]^2}= \tag{S2}$$

$$=\frac{c}{2}\frac{4a\cdot\cosh^2\left(a\left(t-t_0\right)\right)}{\left[\cosh\left(2\left(a\left(t-t_0\right)\right)\right)+1\right]^2}$$

The maximum heating rate occurs at the inflection point, *i.e.*, t=t_0:

$$\frac{\partial T(t)}{\partial t}=\frac{c}{2}\frac{4a}{\left[e^{a(0)}+e^{a(0)}\right]^2}=\frac{ac}{2} \tag{S3}$$

This inflection point is our representative heating rate for a given sample as shown in Figure S5. From Figure S5, the model fits the experimental data until the sample starts to fold. Using this model to find the heating rate, we compare the heating rate of samples with different hinge widths, geometry, orientations, and microwave power as shown in Figure 6.

Screen Printing

Screen printing is a fabrication method used to apply patterned ink to the surface of a flat object. Openings in the screen are patterned with intense light and then the ink is rolled across the surface using a squeegee. The ink can only pass through the patterned parts of the screen and the squeegee keeps the height of the ink uniform. Screen printing allows for precise patterning of the ink onto the surface of the polystyrene samples.

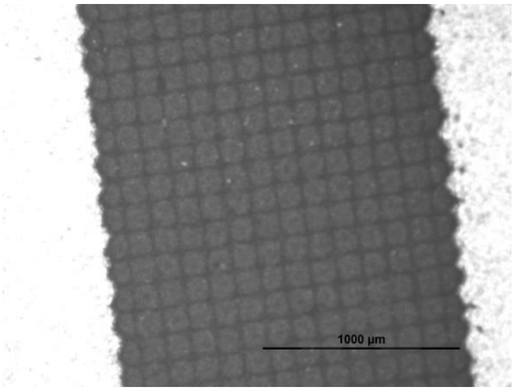


Figure S1. Optical microscopy of the screen printed graphene. There are grid lines from the screen as well as the high level of uniformity in the ink pattern.

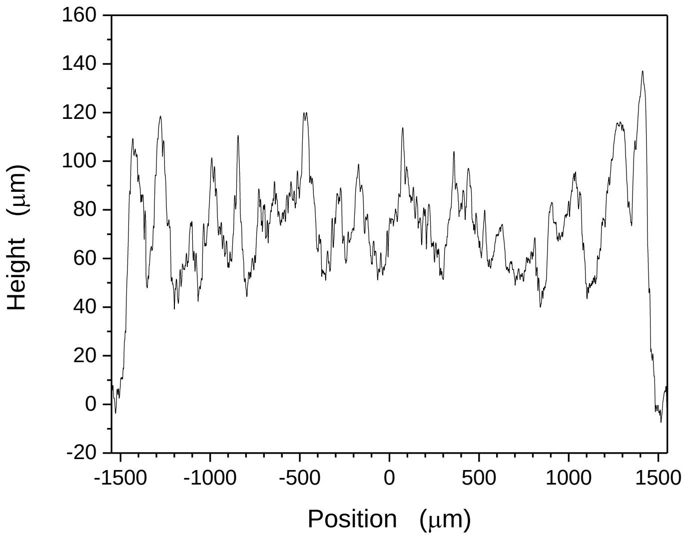
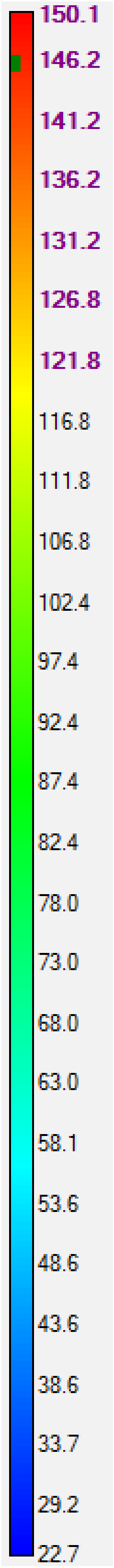


Figure S2. Profilometry of screen printed Vor-ink^{tm} (3 mm hinge width). The hinge size varies from 50 to 100 µm for most peaks in the sample with the maximum being over 130 µm.

Sample heating

The temperature scale on the right is common to both plots.



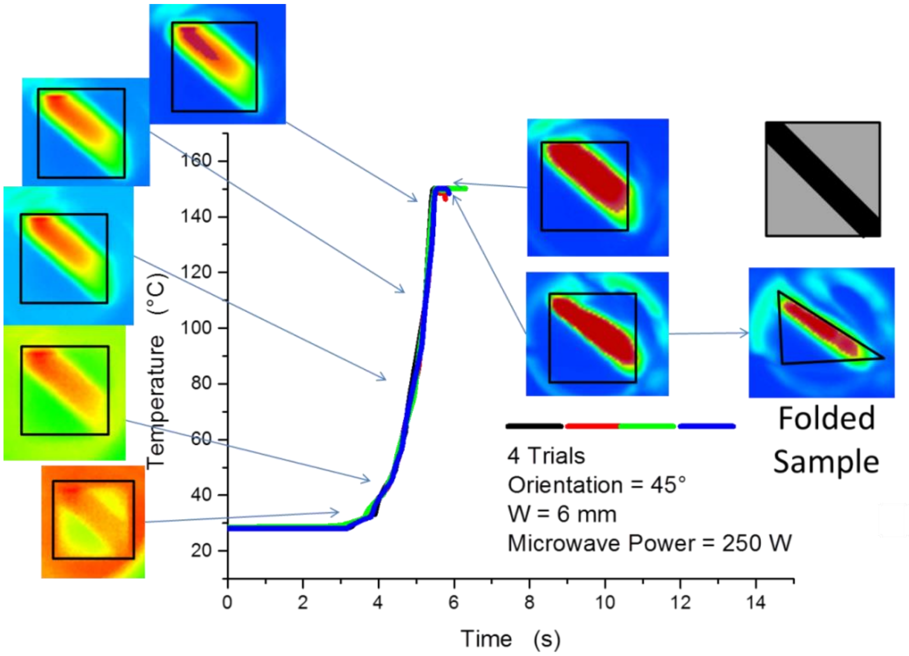


Figure S3. Heating profile for a 'rectangular hinge' (6 mm, 250 W, 45° orientation). The pictures are taken with an IR camera and show how the hinge heated non-uniformly. This lack of uniformity in the profile leads to imperfect folding. The camera view is flipped, so the directional heating is left to right instead of right to left. This sample folds in ~6 second. The microwave is then turned off. (*Note that the first 2 images do not use the same temperature scale in order to increase visibility of the sample and hinge*). The temperature range (in °C) is show in the legend on the right.

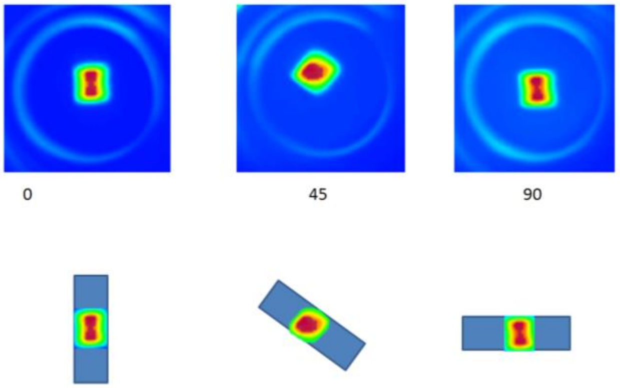


Figure S4. Thermal Images of square hinge samples. Even though the heating rate is similar, the orientation controls whether the sample craters or folds. This is likely because the hot region spans the width of the hinge in the 90° sample (without bound) but is bound by stiff polymer in the 0° case. The temperature range (in °C) is show in the legend on the right.

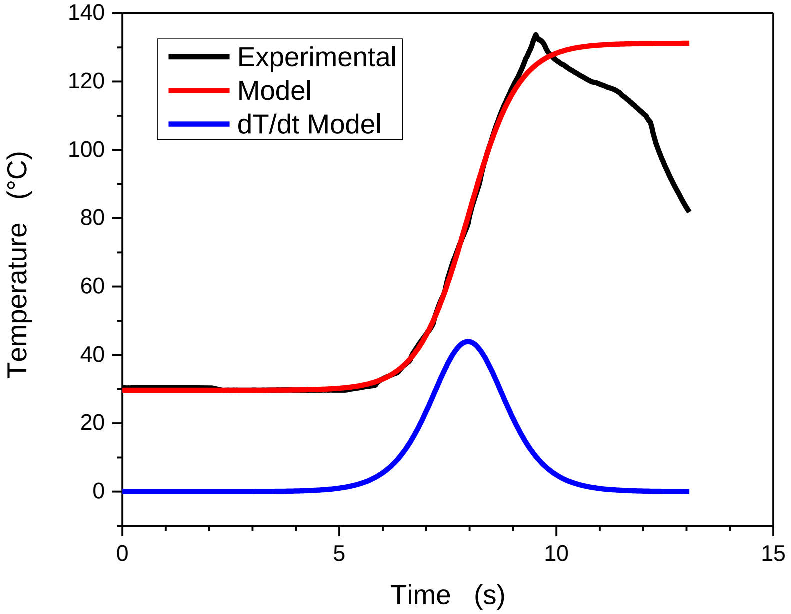


Figure S5. Heating profile of a 3 mm 250 W sample (experimental) and the *tanh* fit. Using this fit we found the maximum heating rate via the inflection point of the derivative.

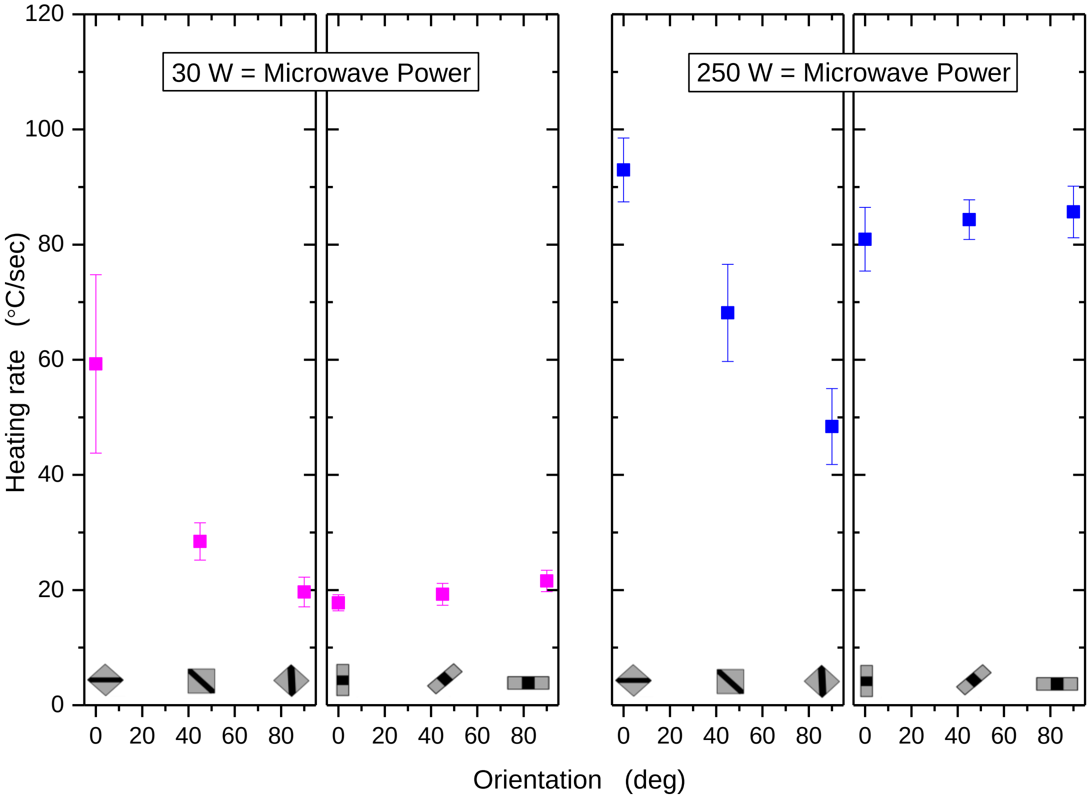


Figure S6. Heating rate of the samples (W = 6 mm) at different microwave powers and orientation relative to the direction of the microwave radiation (azimuthal angle).