Modelling bowing distortion in plastic electronics panels

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Plastic Electronics Fabrication Technologies
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Engineering Science of Films

- Consultancy
  - Started in 2000. One man limited company Emral Ltd based in NE.
  - Now 34 years international experience in films & polymers
- Web Handling
  - Troubleshooting quality issues:
    winding, scratching, bagginess, wrinkling
  - Training
  - TopWeb software support and development
- Film manufacture
- Modelling
  - Film transport and winding
  - Mechanics of flexible electronics and displays (curl, bending)
  - Viscoelastic and temperature dependent mechanics of films
  - VBA (Excel), MathCad, ABAQUS (Finite Elements)

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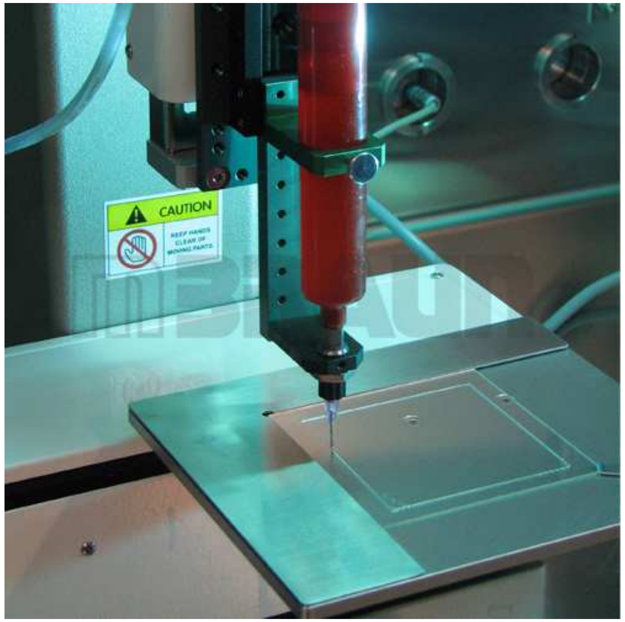
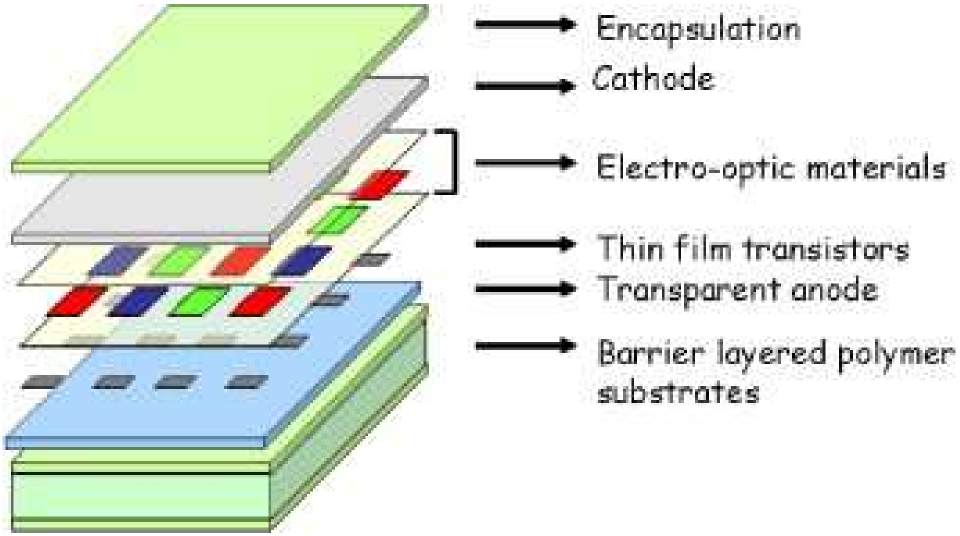
Plastic electronics on glass carrier





- Flexible displays, lighting and photovoltaic cells manufactured on glass carrier, using semiconductor tools.
- Panels “bow” after thermal treatment as low as 60°C
- Lack of flatness causes processing problems
  - Precise placement of electrodes, etc
  - Thermal contact with metal plate
  - Lift <1 mm required

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Why does bowing occur?

- The stack has at least one viscoelastic layer, e.g. PET, PEN
  - Creep: at constant load, the material extends slowly with time
  - Stress relaxation: at constant extension, the stress decays
  - Recovery: slow return to the original size when load is removed.
  - Time-temperature shifting: accelerated when hot, slower when cold.
- Stresses develop in the stack from:
  - Different thermal expansion of layers as the stack heats and cools
  - Residual shrinkage at higher temperature
  - Tension in each layer during lamination
  - Keeping flat, bending over a former or allowing to bend freely
- The stresses are partially set in
  - Model using linear viscoelastic and composite theory
- The stack is released as the final step
  - Internal stresses can partly relieve themselves by bending the panel
  - The bending (bow) changes with time as viscoelastic processes continue.

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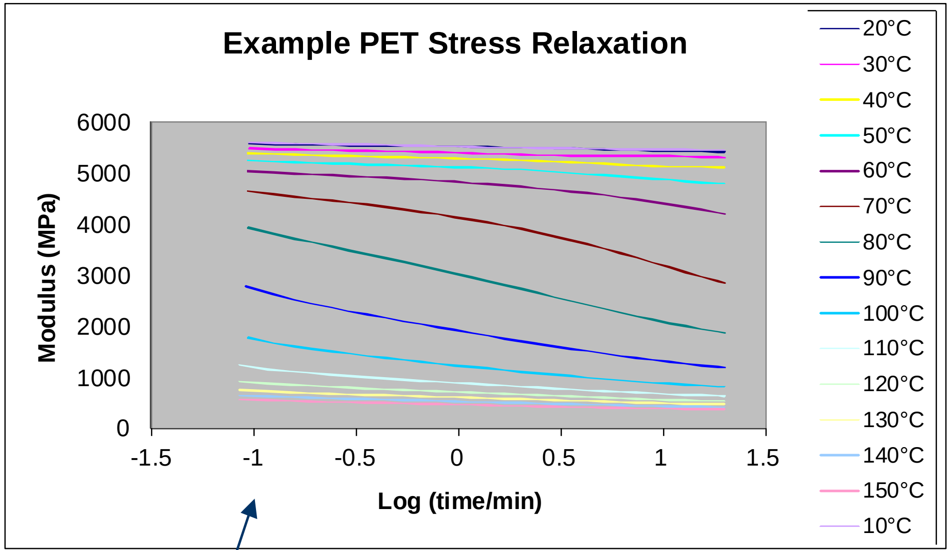
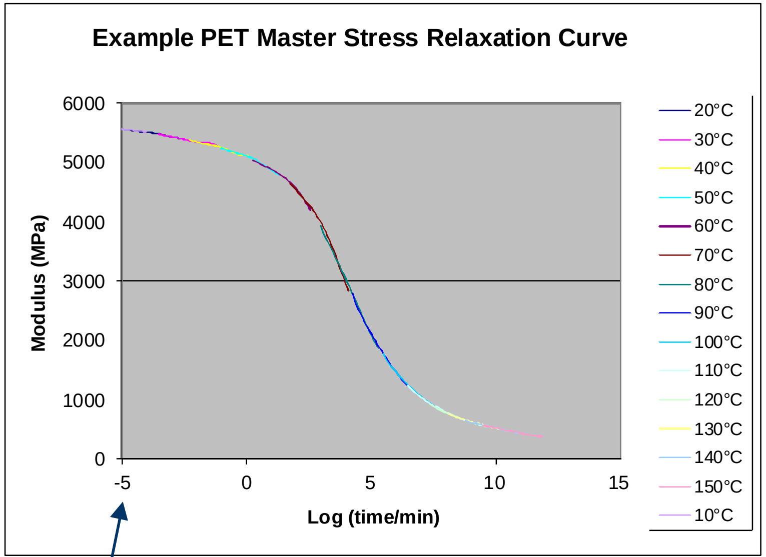
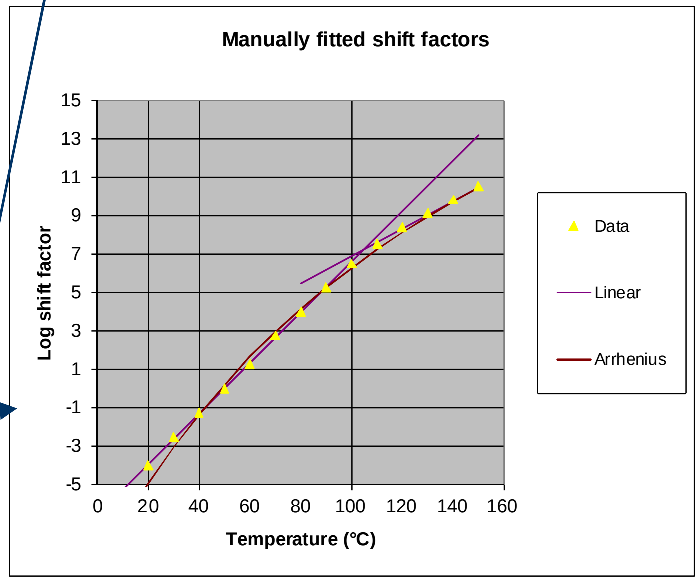
Viscoelastic properties



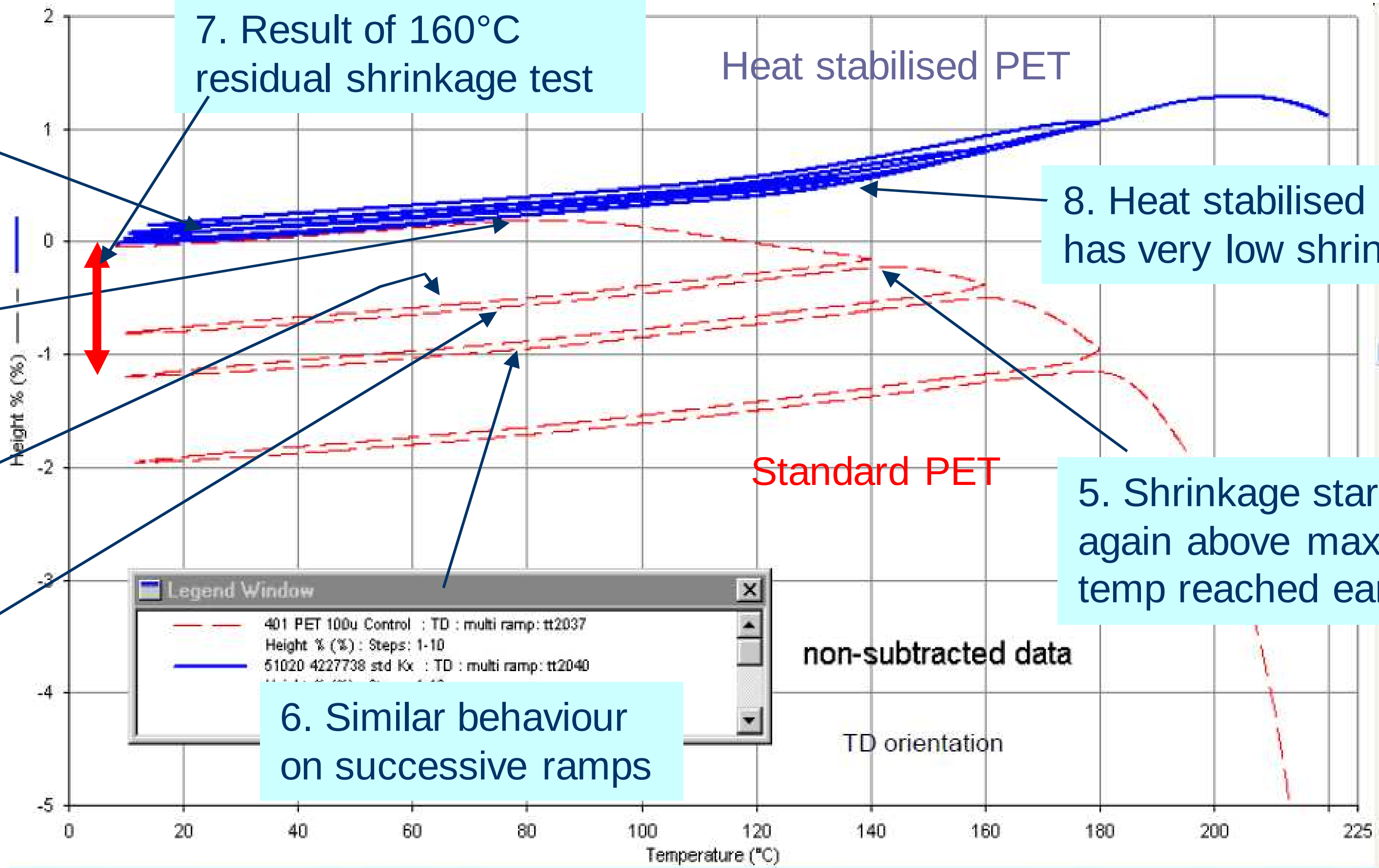


- MD and TD stress relaxation tests
  - By Dynamic Mechanical Analysis (DMA) at Intertek, Wilton
  - 0.2% strain for 30 minutes at 10°C intervals
- Analyse with Excel to give:
  - Master curve and fit with a set of relaxation times (Maxwell-Kelvin springs + dashpots)
  - Shift factor versus temperature curve (Reference temperature 50°C)



Dimension changes with temperature

- TMA (thermomechanical analysis) traces of length versus temperature
- Ramp up to 140, 160, 180°C then down successively, then up to 220°C



1. Reversible thermal expansion below Tg

2. Irreversible shrinkage starts at Tg

3. Cooling reverses thermal expansion only

4. No shrinkage at start of new ramp

5. Shrinkage starts again above max temp reached earlier

6. Similar behaviour on successive ramps

7. Result of 160°C residual shrinkage test

8. Heat stabilised film has very low shrinkage

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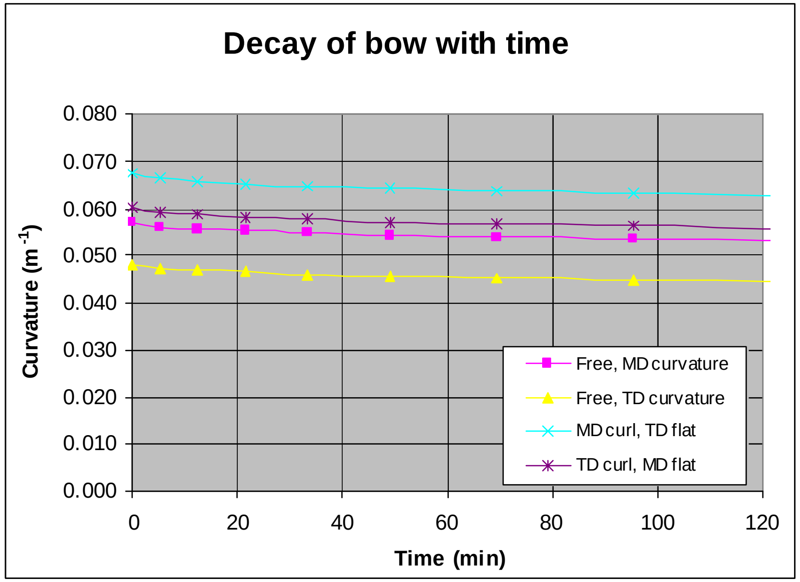
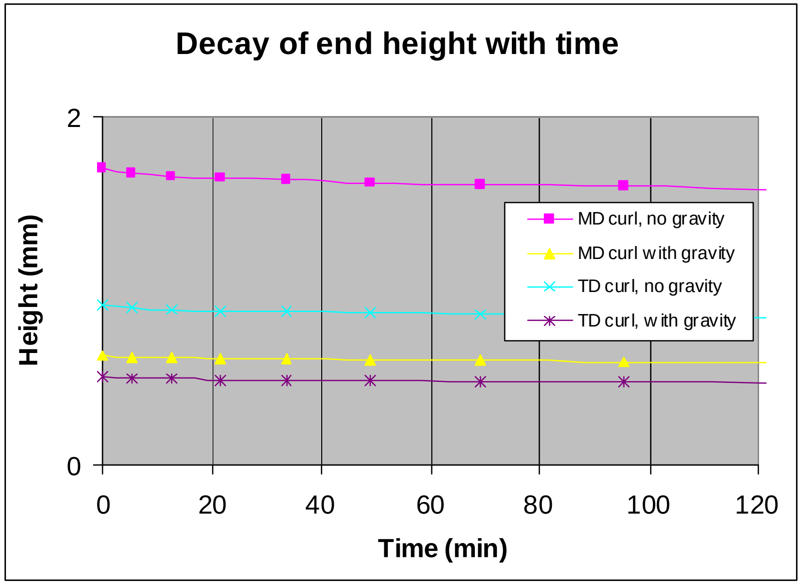
The bowed shape





Plot of curvature (1/radius)

- Model includes anisotropy.
- There is bow tendency in both MD & TD.
- Normally, bow is in one direction only.
- A bowl shape forms if nearly flat. A test value to help choose which occurs. For the exact shape, FE analysis is needed.
- All curvatures decay slightly with time.

Plot of end height

- Gravity pulls the ends down.
- There may be a flat portion in the centre.

The curl of the stack can also be calculated after it is removed from the glass.

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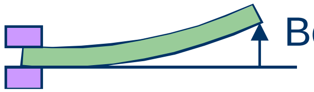
Comparison with experiment

Film	100 μm
Adhesive	48 μm
Film	100 μm
Adhesive	48 μm
Glass	1100 μm



Bow measurement

1. Strips baked for 1 hour

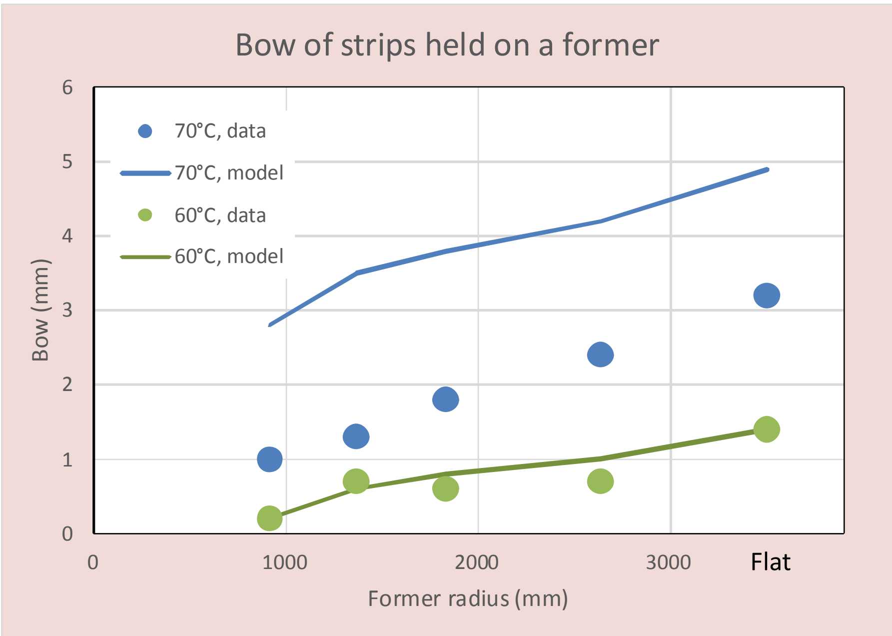
350 x 60 mm

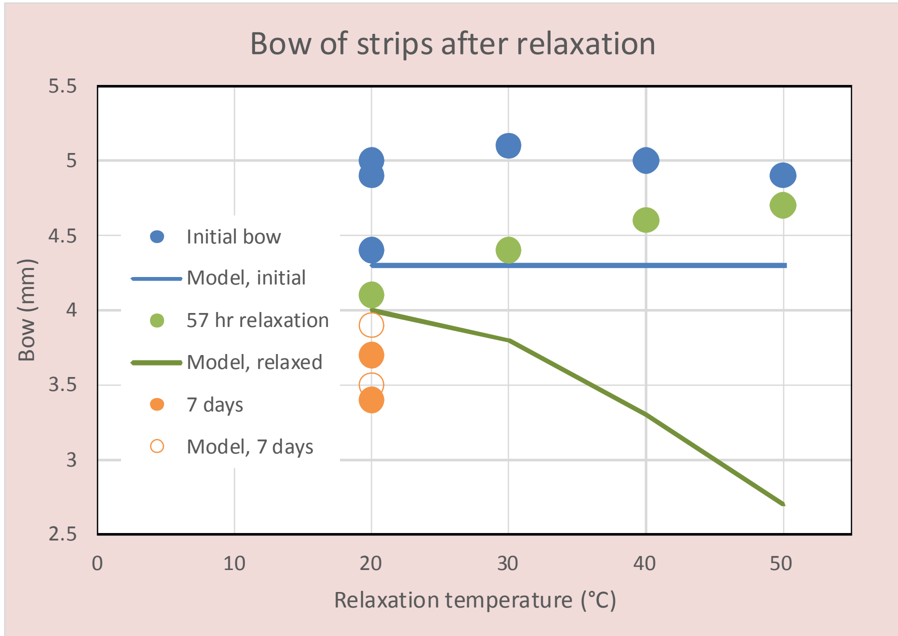
Measured on edge with one end clamped

2. Post-bake relaxation

I hour bake at 70°C
Poor reproducibility

57 hours relaxation (held flat or curved)
Temperature trend is incorrect





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Conclusions

The model is helpful for:

- Predicting the bow of different panel sizes
- Avoiding severe conditions of bake time and temperature
- Forecasting the effect of material changes such as thickness, modulus, expansion and shrinkage.
- Reducing bow with a relaxation step or holding in a curve
- Predicting curl of the flexible elements once removed
- Estimating dimension changes during and after bake.

Agreement with experiment is not perfect:

- Poor reproducibility of bow results
- Film moisture changes during testing cause changes in dimensions and viscoelastic rates
- Incomplete and possibly inaccurate data
- Shear/slip in adhesive

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General Remarks

- Dimensional stability issues are not completely removed by processing on glass.
- Issues arise from thermal expansion and viscoelasticity even below T_g.
- Residual shrinkage adds to the problem above T_g.
- Moisture also has an effect on dimensional stability and bow.

The model was developed for:

- DuPont Teijin Films
- Plastic Logic

Thanks for permission to present.

Thank you for listening!

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