Indirect determination of the degree of EVA cross-linking with a hardness test

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Abstract
The Shore hardness parameter is proposed as an analogue for the degree of cross-linking in ethylene vinyl acetate (EVA) sheets. The parameter is measured for a series of EVA sheets, both individually and as part of a mini-module. The gel content, which is another analogue of cross-linking, is measured using the Soxhlet test and correlated with the hardness index. To obtain a range of cross-linking behaviors, samples were cured for different periods. It has been shown the Soxhlet measurement correlates with the Shore D0 hardness. We conclude that the hardness test is a viable alternative to the Soxhlet measurement for PV-manufacture.

Background/Approach
The approach is based on a Shore D0 hardness measurement: a force-loaded indentor (44.5 N) with a ball-shaped head (Ø2.38 mm) makes an indention in a surface and the penetration depth is measured.

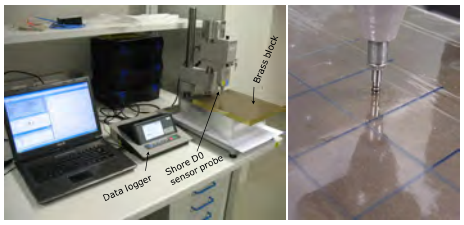

Figure 1: Shore D0 hardness set-up

On the assumption that differently cured EVA samples have different mechanical properties, the measured hardness is related to the effect of cross-linking in the polymer network.

Results
Six samples with different curing times were prepared: uncured, two, four, six, eight and ten minutes. Each sheet was cut into three separate pieces. On each piece measurements are made at 25 points in a grid to create an interpolated hardness map.

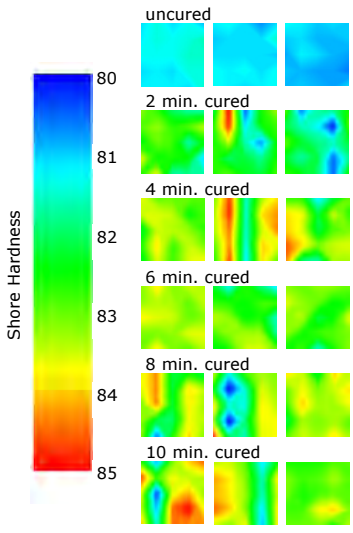

Figure 2: Hardness test on EVA specimens

The six test samples, each cut in three pieces, were subjected to the Soxhlet test, and the average gel content plotted for each curing time, Figure 3.

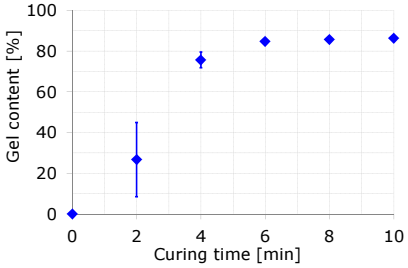

Figure 3: Soxhlet test on EVA

The Shore D0 hardness results are plotted against gel content, Figure 4.

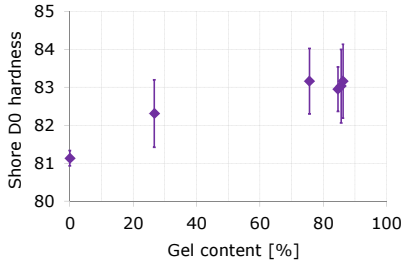

Figure 4: Shore D0 hardness on EVA samples

The measurements, carried out on separate EVA sheets, were repeated on a complete mini-module with back sheet, EVA, one solar cell, EVA and glass.

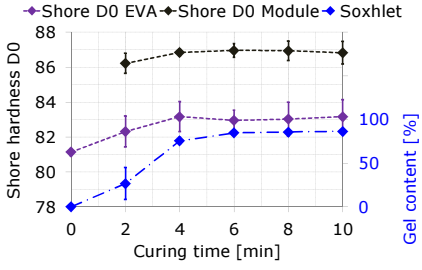

Figure 5: Comparison of the measurements Soxhlet and Shore D0

The measurements of the six minutes laminate, before and after the hardness measurement, is shown in Figure 6. Four of the six measurement points show damage.

Figure 6: Laminated cell of the 6 minutes sample before and after the Shore D0 test

A simulation was done to find whether the parameters of the Shore D0 test could be changed to avoid damaging the module.

Simulation

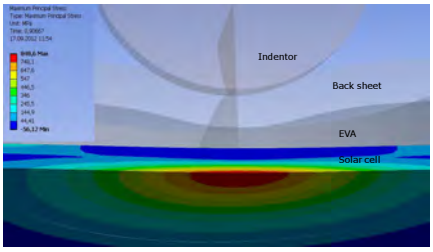

Figure 7: Simulation of the stress in the solar cell meanwhile a Shore D0 hardness test; view from beneath

We assume that silicon will not fracture for stresses below 200 MPa. From Figure 8, this limits the force to 10 N, where the critical stress range is undershot.

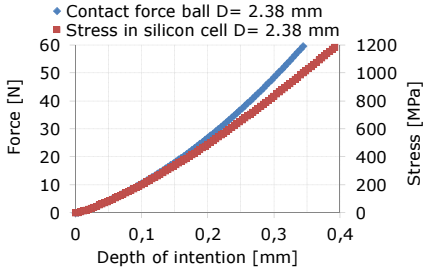

Figure 8: Simulated stress in a laminated cell caused by the Shore D0 method depending on force.

Conclusion
The Shore D0 hardness method is an alternative to replace the Soxhlet test. Shore D0 is relatively fast (20 minutes for 15 measurements) and no chemicals are needed. The applicability for modules is in the early stages and need to be improved to reduce the damage inflicted on the solar cell in the module.

Acknowledgements
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