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Full title: Round Robin testing of various back-sheets for PV-modules with different ultra-violet radiation sources and sample temperatures

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Summary:

Durability testing of materials exposed to natural weathering requires testing of the UV stability, especially for polymeric materials. The type approval testing of PV-modules according to the standards IEC 61215 and IEC 61646 includes a so-called UV-preconditioning test with a total UV dose of 15 kWh/m² not corresponding to the real loads during lifetime. Between 3- 10% of the UV radiation has to be in the spectral range between 280nm and 320nm in the recent editions of the standards. However, the spectral distribution of the radiation source is very important since the samples show a very individual spectral sensitivity for the radiation offered. Less than 6% of the intensity of solar radiation comes in the UV range. In case of an increase of the intensity of the light source for accelerating the UV-test the overheating of the samples would have to be prevented more strictly and the temperature of the samples have to be measured in order to avoid misinterpretation of the test results.

Fraunhofer ISE organised an inter-laboratory comparison of testing different back-sheets with different UV-light sources in various test laboratories using different UV-sources. The interaction of the UV-radiation with the polymers used in PV-modules is main subject of this round robin. Laminates were produced by using solar glass (130mm * 200mm) and a respective EVA encapsulant combined with 7 different back-sheets. The sample was exposed in a sample holder equipped with a couple of different filters in order to investigate roughly the spectral sensitivity by means of 3 edge filters and the intensity impact by two grating filters. The sample temperature was measured by thermo-couples.

The degradation was followed by spectral reflectance and transmittance measurements and calculation of the yellowness-index. Clear differences in the degradation behavior of the different products were found.

1 Introduction

Durability testing of materials exposed to natural weathering requires testing of the UV stability, especially for polymeric materials. The type approval testing of PV-modules according to the standards IEC 61215 [1] and IEC 61646 includes a so-called UV-preconditioning test with a total UV dose of 15 kWh/m², comparable to 3 months weathering in moderate climates, but not corresponding to the real loads during lifetime. Between 3-10% of the UV radiation has to be in the spectral range between 280nm and 320nm (UV-B) in the recent editions of the standards. However, the spectral distribution of the radiation source is very important since the samples show a very individual spectral sensitivity for the radiation offered. Less than 6% of the intensity of solar radiation comes in the UV range. In case of an increase of the intensity of the light source for accelerating the UV-test the overheating of the samples would have to be prevented more strictly and the temperature of the samples have to be measured in order to avoid misinterpretation of the test results.

2 Experimental

Fraunhofer ISE organised an inter-laboratory comparison of testing different back-sheets with different UV-light sources in various test laboratories using different UV-sources. The interaction of the UV-radiation with the polymers used in PV-modules is main subject of this round robin. Laminates were produced by using solar glass (130mm * 200mm) and a respective EVA encapsulant combined with 7 different back-sheets. One special laminate was produced with a thermoplastic silicone and an appropriate back-sheet for comparison. Besides the laminates single back-sheet samples were exposed with the side dedicated to adhere to the encapsulant in addition to the laminates that had been exposed via the glass-side and the unprotected back-side, both.

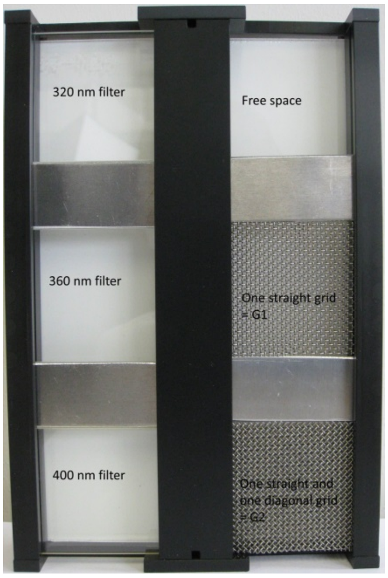

Figure 1: Sample holder equipped with edge filters (left side) and intensity filters (right side)

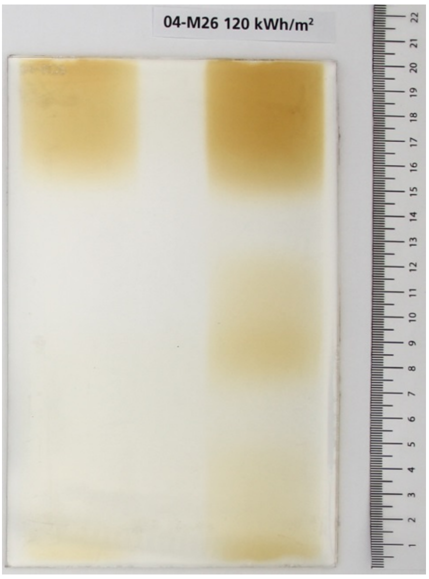

Figure 2: Example of yellowing of a back-sheet below different filters after a UV-irradiation of 120 kWh/m²

The samples were exposed in a sample holder equipped with a couple of different filters (50mm*50mm each) in order to investigate roughly the spectral sensitivity by means of 3 edge filters and the intensity impact by two grating filters (G1 with an average transmittance of 56% and G2 with an average transmittance of 32%, see figure 1 and figure 2). The sample temperature was measured by thermo-couples and the plan was to achieve different sample temperatures by setting different ambient chamber temperatures (60°C and 80°C) in order to evaluate the temperature dependence of the photo-degradation.

The degradation was followed by spectral reflectance and transmittance measurements and calculation of the yellowness-index.

3 Results

The degradation was followed by spectral reflectance and transmittance measurements (Fig. 3) and the calculation of the yellowness index. Clear differences were found in the degradation behaviour of the different products.

Some samples did not change after a UV dose of 120 kWh/m² (see Fig. 3), indicating that the EVA does not show a visible degradation, whereas others showed intense discoloration (Figs. 2 and 4).

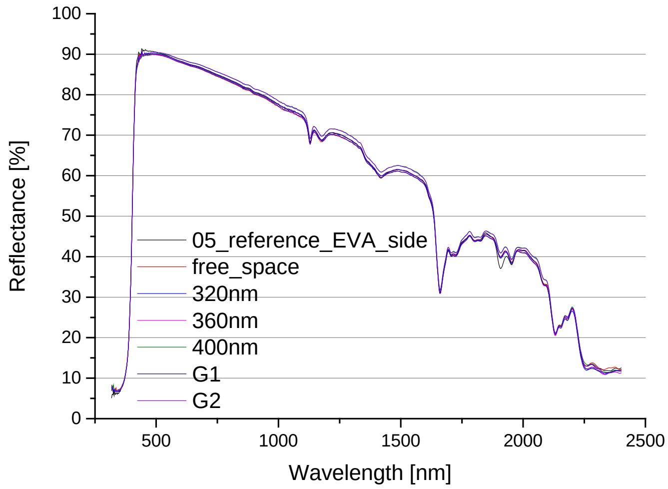

Figure 3: Spectral reflectance of a backsheet after a UV irradiation of 120 kWh/m² behind the different filters.

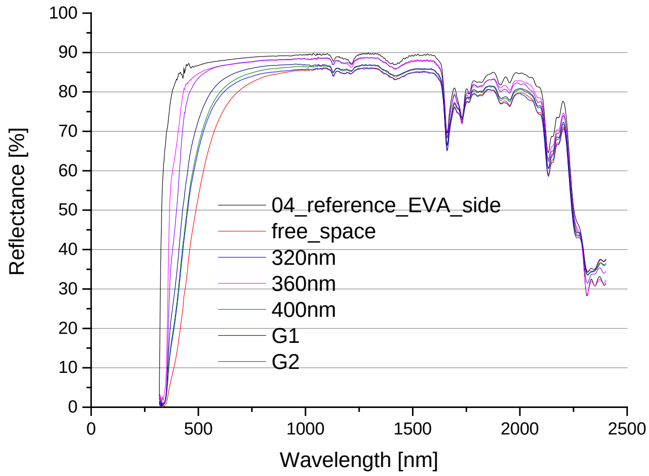

Figure 4: Spectral reflectance of a less stable backsheet after a UV irradiation of 120 kWh/m² behind the different filters.

No discoloration was found in Fig. 2 behind the 360-nm and 400-nm filters. The same effect can be seen in the YI diagrams for the most degraded samples, too (e.g. figure 5 and 6), indicating that these samples are not sensitive against radiation with wavelengths longer than 360nm.

The results among the laboratories show significant differences. For example, the yellowness index showed differences up to a factor of 3 (Fig. 5 and Fig. 6) depending on the sample.

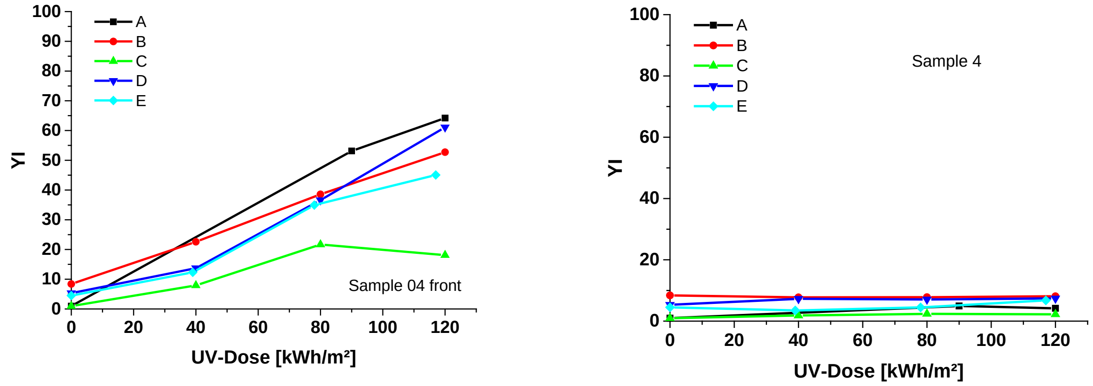

Figure 5: Example of the changes of the yellowness index of the backsheet #04 in 5 different test labs up to a UV dose of 120 kWh/m² without filter and behind cut-off at 360nm (right).

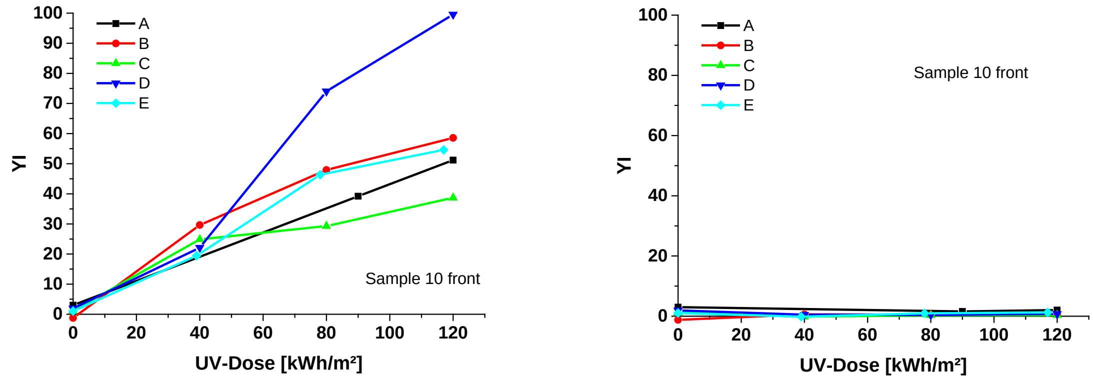

Figure 6: Example of the changes of the yellowness index of the backsheet #10 in 5 different test labs up to a UV dose of 120 kWh/m² without filter and behind cut-off at 360nm (right).

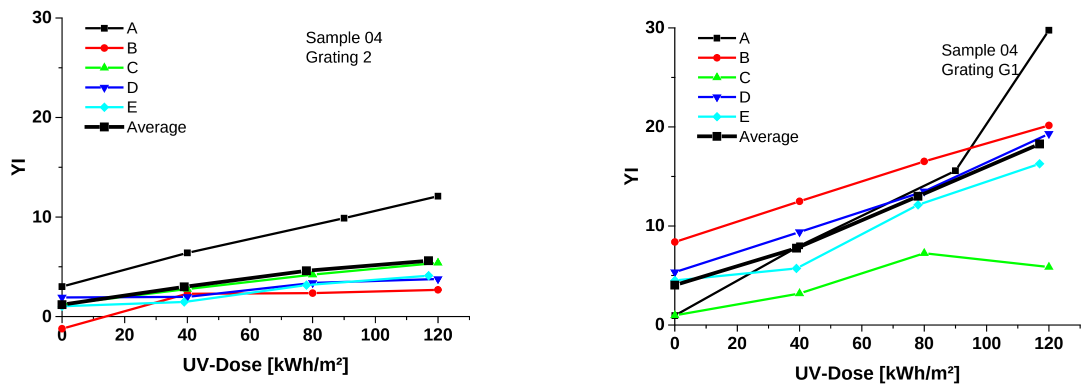

Figure 7: Example of the changes of the yellowness index of the backsheet #04 in 5 different test labs up to a UV dose of 120 kWh/m² without filter behind grey filter G1 and G2.

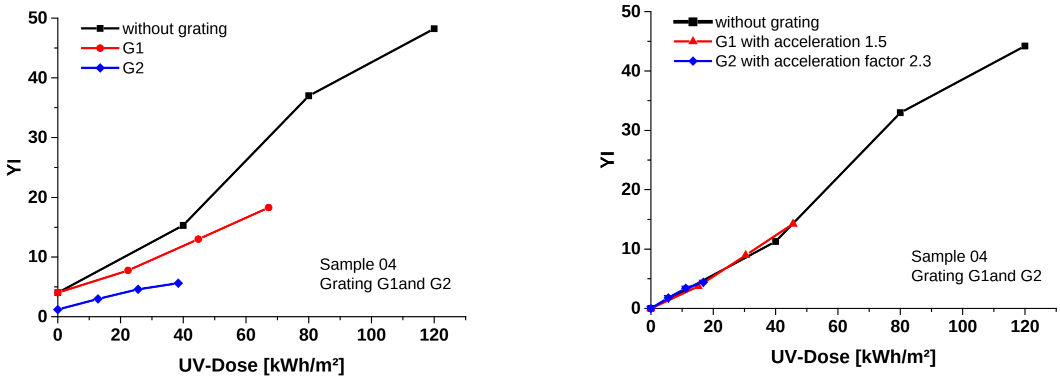

Figure 8: Average changes of the yellowness index of the backsheet #04 from 5 different test labs up to a UV dose of 120 kWh/m² without filter and behind grey filter G1 and G2 (left diagram) and transformation of the curves by means of acceleration factors (right diagram).

The shading by the intensity filters clearly reduced the discoloration (Fig. 7). The increasing scattering of the results of the different labs recommended averaging of the results. An acceleration by increasing intensity of 1.5 for the difference between filter G1 and full intensity and 2.3 related to G2 was evaluated by matching the degradation functions at the different intensity levels (see Fig. 8) for sample #04. The sample temperature depends on the absorptance of the materials, the spectra of the UV sources, and the temperature distribution in the test cabinet and could contribute an additional acceleration besides the intensity. But the difference between sample areas with and without grating is only about 2 Kelvin (see Fig. 9) for white backsheets, which cannot be the reason for the evaluated acceleration and contribute 10% of the evaluated acceleration in maximum for an activation energy of 40 kJ/mol.

Usually the UV-intensity I is not correlated linearly with the damage but follows a power law:

Acceleration factor $a_x(I,t) = (I_0/I_x)^n$ (1)

With the unknown exponent n. For the sample #04 the factor n = 0.7 could be evaluated.

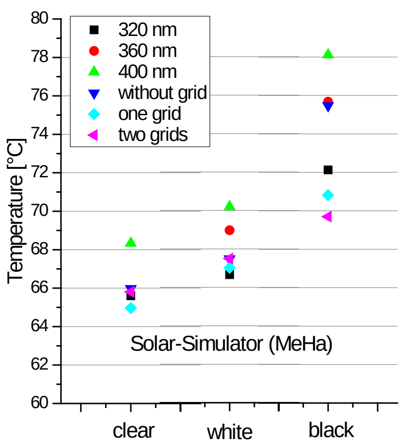

Figure 9: Sample temperature of differently colored backsheet/ encapsulant/glass laminates applying solar simulating metal-halide lamps.

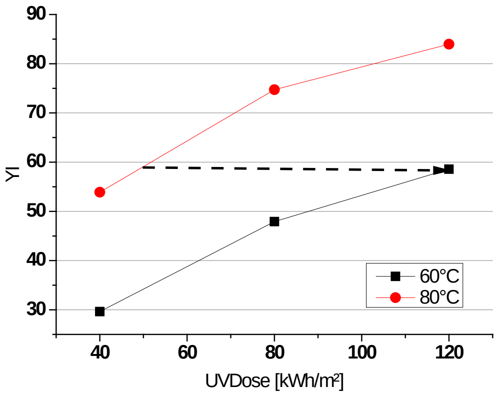

Figure 10: Trend of yellowness index at different sample temperatures.

Tests carried out at different sample temperatures allowed evaluation of the acceleration factor and the activation energy (Fig. 10). The activation energy for the temperature-dependent degradation kinetics is in the order of 40 kJ/mol and offers the possibility to accelerate service life tests without using very high radiation intensities, but increasing the sample temperature during irradiation.

Conclusions

Basic ideas about spectral sensitivity of materials could be gained.
The UV stability for some of the samples could be proven.
The round-robin test showed large differences in the results depending on the different UV sources in the participating laboratories and the different sensitivity of the samples. The results have to be further evaluated and the tests need to be completed.
The radiation with wavelengths longer than 360nm did not cause any photo-degradation.
The UV intensity follows a power-law with an exponent smaller than unity.
Testing at different sample temperature allows the evaluation of the acceleration factor and modelling of the kinetics of the degradation processes and enables accelerated service life testing.

Acknowledgments

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References

[1] IEC 61215 ed. 3
[2] Michael Koehl and Daniel Philipp, Inter-laboratory comparison of UV-light sources for testing of PV-modules, Prog. Photovolt: Res. Appl. (2015), DOI: 10.1002/pip.2624