# Reliability and durability comparison of PV module backsheets

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## ABSTRACT

The backsheet is the first barrier for ensuring the reliability and durability of PV modules for 25+ years. To reduce cost, backsheets with a variety of compositions and constructions have been developed and introduced in PV modules. For PV module manufacturers, a major challenge is choosing a low-cost backsheet that can maintain the current levels of high reliability and durability performance. In the work reported in this paper, the properties of several backsheets of various compositions and constructions were compared. To distinguish the different backsheet properties, intensive and long-term weathering tests were performed. The results showed that the backsheet properties had a significant influence on the durability of the material. The ability of a backsheet to withstand extended high-humidity exposure is mainly affected by the hydrolysis performance of the core layer PET material, and is not affected by the outer layer material. Some backsheets – such as PVDF/PET/PVDF and PVF/PET/PE, which use a modified PE as the inner layer – also demonstrated a high ability to withstand extended UV exposure; PET-based backsheets, on the other hand, exhibited poor tolerance to UV exposure. In terms of weatherability, PA-based backsheets performed the worst.

## Introduction

PV modules have a designed service life of at least 25 years, throughout which they will suffer a variety of environmental effects, such as high temperatures, high humidities and UV exposure. The module encapsulant material is expected to take up the challenge of ensuring long-term reliability and durability during the designed service life. The backsheet, as the outer layer of a PV module, is especially important for providing protection to the module in order for it to survive during its expected service life.

"Extensive testing is required in order to determine if the new types of backsheet can provide the same protection as the well-established PVF/PET/PVF backsheet."

In the past, the multilayer structure comprising polyvinyl fluoride / polyester ethylene Tedlar / polyvinyl fluoride (PVF/PET/PVF) has been used for backsheets of PV modules because of its proven long-term outdoor performance [1]. Since 2005, in an effort to reduce cost, backsheets with different compositions and constructions (other fluoropolymer films, non-fluoropolymer films, coatings, etc.) have been developed and introduced in PV modules; however, a long-term experience of the service life of some of the newer backsheets when used in PV modules is lacking. Extensive testing is therefore required in order to determine if the new types of backsheet can provide the same protection as the well-established PVF/PET/PVF backsheet.

This paper presents an evaluation of the durability of these new backsheets,

| Sample | Layer composition and construction | Layer thickness [μm] |
|---|---|---|
| 1 | PVF / PET (PCT<36h) / PVF | 38 / 250 / 38 |
| 2 | PVDF / PET (PCT 48h) / PVDF | 30 / 250 / 30 |
| 3 | PVF / PET (PCT 60h) / PE (from PE supplier A) | 25 / 250 / 60 |
| 4 | PVF / PET (PCT 48h) / PE (from PE supplier A) | 25 / 250 / 60 |
| 5 | PVDF / PET (PCT 48h) / PE (from PE supplier D) | 20 / 250 / 60 |
| 6 | PVDF / PET (PCT 36h) / PE (from PE supplier E) | 20 / 250 / 60 |
| 7 | ETFE / PET (PCT<36h) / PE | 25 / 188 / 110 |
| 8 | PVDF / PET (PCT 48h) / fluorine coating | 25 / 255 / 4 |
| 9 | Fluorine coating / PET (PCT 60h) / fluorine coating | 25 / 250 / 15 |
| 10 | Non-fluorine coating / PET (PCT 48h) / PP | 2 / 125 / 150 |
| 11 | PET / PET(PCT 60h) / PE (from PE supplier F) | 50 / 125 / 100 |
| 12 | PA / PA / PA | 350 (total) |

PA = polyamide; PE = polyethylene; PET = polyethylene terephthalate; PVDF = polyvinylidene fluoride; PVF = polyvinyl fluoride; ETFE = ethylene tetrafluoroethylene; PP = polypropylene.

**Table 1. Composition and construction of the various backsheets tested.**

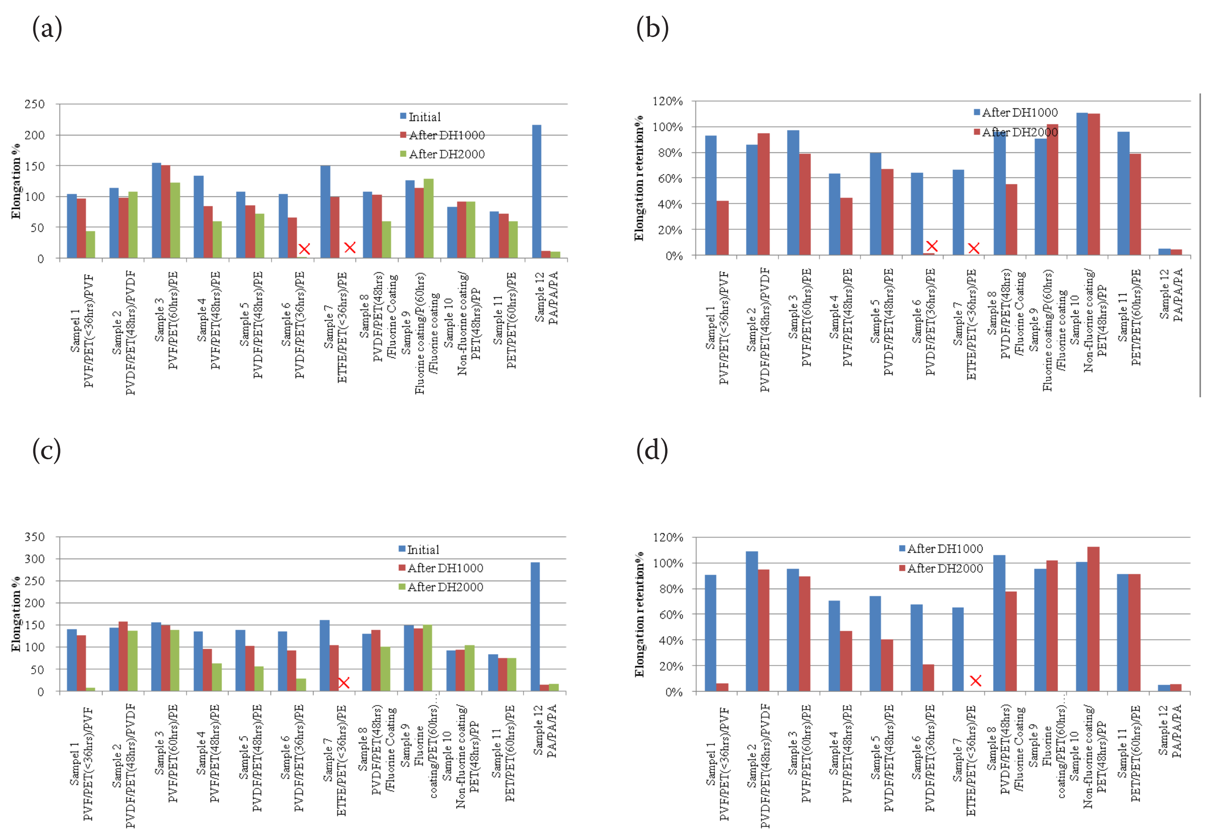



**Figure 1. Comparison of elongation and elongation retention before and after the damp-heat tests: (a) TD elongation; (b) TD elongation retention; (c) MD elongation; (d) MD elongation retention.**

with PVF/PET/PVF as a baseline. To distinguish the different backsheet properties, intensive and long-term weathering tests were performed: 2000h of damp heat, 400 cycles of thermal cycling, 40 cycles of humidity–freeze and more than 120kWh/m$^2$ of UV exposure.

## Experimental set-up

### Selection and classification of backsheets

Table 1 shows the different compositions and constructions of the tested backsheets that have been commercialized in the PV industry. All the backsheets, with the exception of PA/PA/PA, use modified PET as the core layer, which provides a barrier to moisture. PET is sensitive to moisture and prone to hydrolysis; hence modified PET can improve the hydrolysis resistance performance. Usually, PET suppliers use a pressure cooker test (PCT), consisting of 120°C and 100% relative humidity (RH) at 2 atm, to assess the hydrolysis resistance of PET. The elongation of PET is measured before and after the PCT test, until the elongation retention is below 40%; the test period then represents the hydrolysis resistance level of the PET.

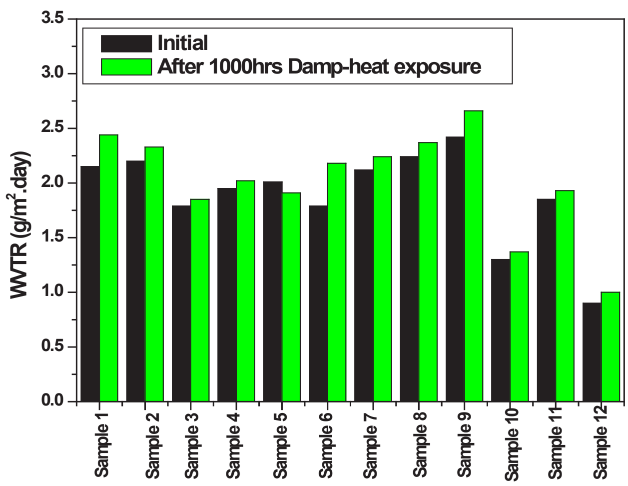



**Figure 2. WVTR before and after 2000h damp-heat testing.**

## Experimental methods

### Mechanical properties

The elongation of the backsheets was measured using an INSTRON 3365: the elongation in the transverse direction (TD) and machine direction (MD) of free-standing films was measured in accordance with ASTM D882. If the elongation retention of a backsheet is below 40%, the backsheet is usually considered to have failed the test.

Elongation was measured before and after damp-heat, thermal-cycling and humidity–freeze tests, which were conducted in accordance with IEC 61215 [2]:

- Damp heat: 85°C and 85% RH
- Thermal cycling: –40°C to 85°C
- Humidity–freeze: –40°C to 85°C and 85% RH

### Optical properties

The colour coordinate *b** and the metallographs were measured before and after UV exposure. The inner layer

PV Modules

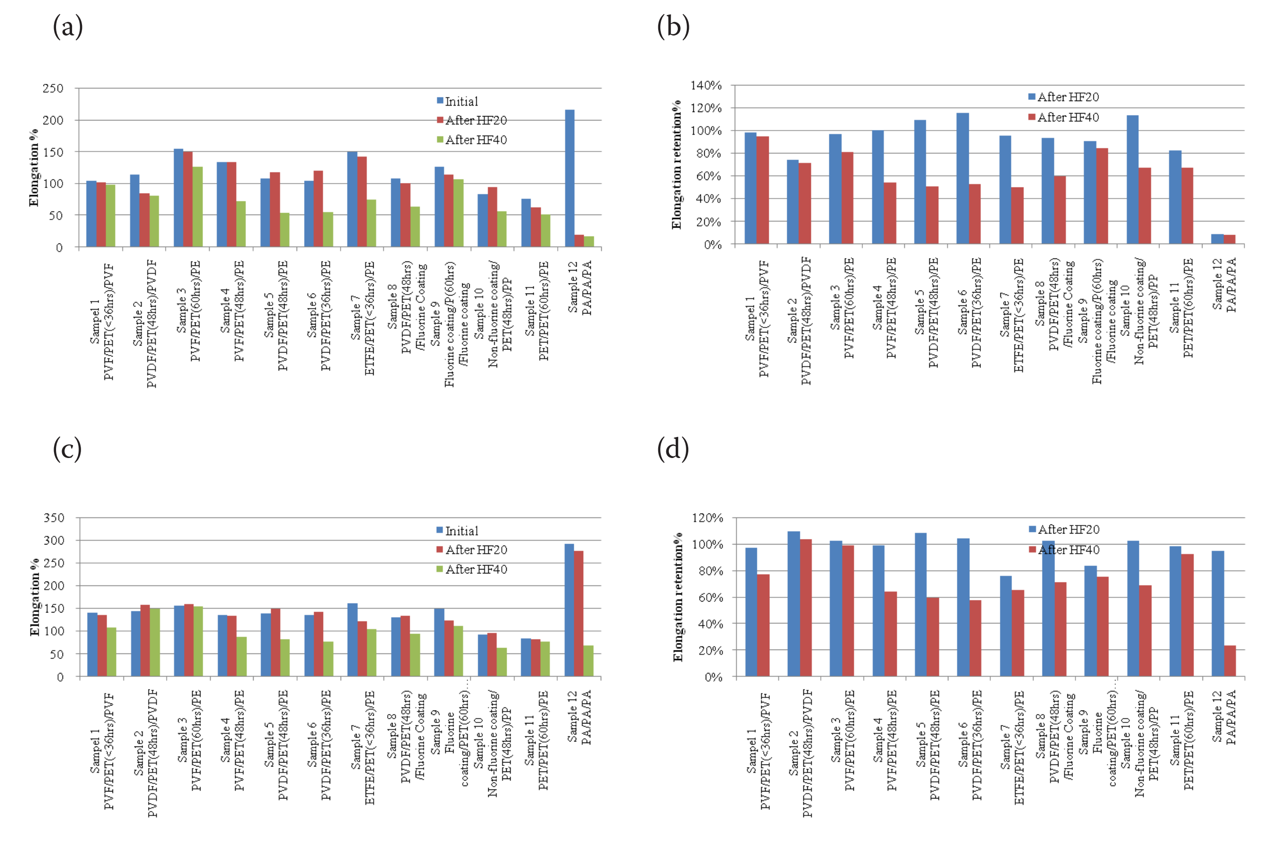



**Figure 3. Comparison of elongation and elongation retention before and after the humidity–freeze tests: (a) TD elongation; (b) TD elongation retention; (c) MD elongation; (d) MD elongation retention.**

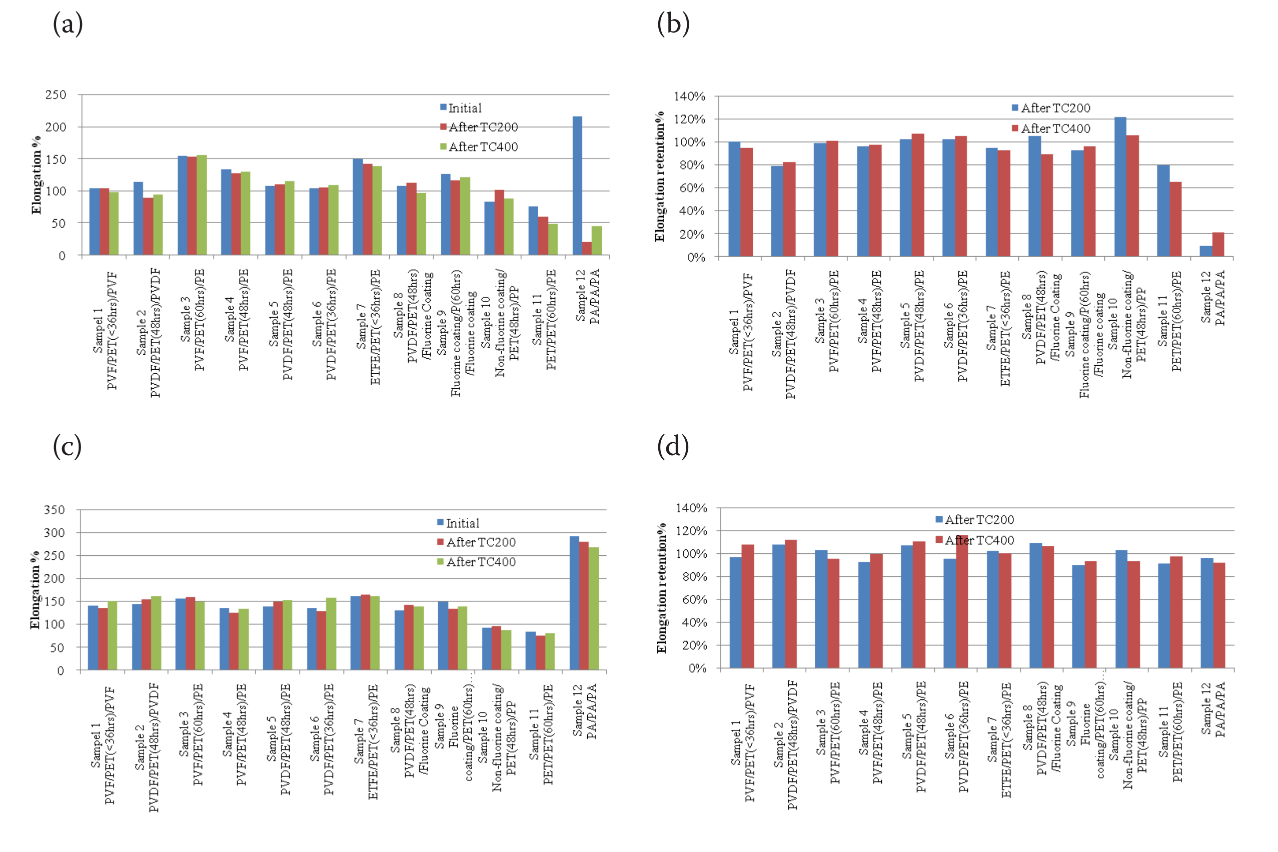



**Figure 4. Comparison of elongation and elongation retention before and after the thermal-cycling tests: (a) TD elongation; (b) TD elongation retention; (c) MD elongation; (d) MD elongation retention.**

of the backsheet can be affected by the amount of UV light exposure, which will cause an aesthetic defect in the module and can lead to embrittlement and reduced dielectric strength.

The UV test (wavelength 280–400nm, with 3–10% UV irradiance in the wavelength range 280–320nm) was also conducted in accordance with IEC 61215 [2].

### Water vapour transmission rate (WVTR)

The WVTR was measured using MOCON, with test conditions of 38°C and 100% RH. The barrier moisture property of the backsheet is important, since EVA encapsulants can produce acetic acid under moisture exposure; this can accelerate corrosion of the electrical components of the PV module and cause power degradation.

## Results

### Damp-heat impact on backsheets

The results of a comparison of TD and MD elongation of free-standing backsheet films before and after damp-heat testing are shown in Fig. 1. Sample 1 (PVF/PET/PVF backsheet) is used as the baseline. Apart from Sample 12 (PA/PA/PA), all the backsheets after 1000h damp-heat testing demonstrated a good elongation and elongation retention, similar to Sample 1.

> "The common component of the failed backsheets is the use of PET with a lower hydrolysis resistance performance (PCT 36h or <36h) as the core layer."

After 2000h of damp-heat testing, however, the elongation and elongation retention of Sample 1 began to decrease: in the MD in particular, the elongation retention was only 6%. Sample 6 (PVF/PET/PE) and Sample 7 (ETFE/PET/PE) also showed less than 40% of elongation retention in both the TD and the MD. The common component of the failed backsheets is the use of PET with a lower hydrolysis resistance performance (PCT 36h or <36h) as the core layer.

Other backsheets using PET with a high hydrolysis resistance (PCT 48h and PCT 60h) as the core layer showed higher elongation retention after 2000h damp-heat testing. Note that Samples 3 and 4 are from the same backsheet supplier and have the same composition, construction and processing technique, the only difference being the hydrolysis resistance of the core layer PET. Sample 3 uses a higher hydrolysis resistance PET (PCT 60h) than Sample 4 (PCT 48h), resulting in significantly better mechanical properties.

The results indicate that the performance of backsheets using PET as the core layer in withstanding humidity is mainly affected by the hydrolysis resistance performance of PET. The PA/PA/PA backsheet performs very poorly in resisting humidity.

The backsheets also underwent WVTR testing before and after the 2000h damp-heat tests; the results are shown in Fig. 2. In all cases there was only a slight increase in the value of WVTR after exposure to 2000h damp heat, although some backsheets demonstrated low elongation and elongation retention. The barrier moisture property does not therefore correlate with obvious degradation.

### Humidity–freeze impact on backsheets

The elongation properties in the TD and MD of free-standing backsheet films after humidity–freeze tests were measured; the results are shown in Fig. 3. Sample 12 (PA/PA/PA) showed poor weatherability performance once again; other backsheets were able to maintain a good elongation and elongation retention, even when the humidity–freeze test was prolonged to 40 cycles.

### Thermal-cycling impact on backsheets

The results of 400 cycles of thermal-cycling are shown in Fig. 4: it can be observed that the ability to withstand thermal-cycling is mainly influenced by the composition of the backsheet material. Only the backsheet using PA material showed poor durability in the TD to the temperature stress; other backsheets, using PET as the core layer, demonstrated excellent temperature stress performance, similar to that of the baseline PVF/PET/PVF.

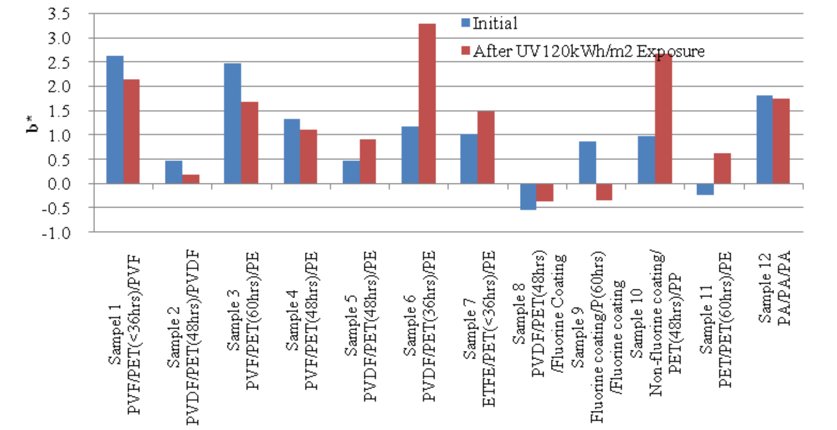



**Figure 5. Colour coordinate b* before and after UV exposure.**

**Figure 6. White powder from the Tedlar surface, observed after 330kWh/m2 of UV exposure.**

## UV irradiance impact on backsheet

To simulate UV exposure from the front side, the EVA sides of free-standing backsheet films were exposed to prolonged UV exposure of more than 120kWh/m$^2$; the colour changes are shown in Fig. 5. Only Samples 6 and 10 demonstrated a significant change in colour after 120kWh/m$^2$ UV exposure, with all other backsheets showing low levels of colour change. Backsheets using PE or a fluorine coating on PA as an inner layer exhibited a lower level of colour change than TPT backsheets.

> "Backsheets using PE or a fluorine coating on PA as an inner layer exhibited a lower level of colour change than TPT backsheets."

The authors believe that the measured level of colour change will not accurately reflect the actual ageing of backsheet material in the field. It was noted that although some backsheets showed a low level of colour change, cracking was still observed (see the metallographs in Tables 2 and 3). For example, the level of colour change of Sample 11 (PET/PET/PE) is low, but obvious cracking was observed after 45kWh/m$^2$ of UV exposure. Cracking was also observed in both Sample 5 (PVDF/PET/PE) and Sample 6 (PVDF/PET/PE) after 120kWh/m$^2$ of UV exposure, but the level of colour change of Sample 5 was lower than that of Sample 6. There is no correlation between the colour change and the extent of the cracking. It is therefore speculated that some additives in backsheets can reduce the visible colour change, even if the materials have degraded.

## Metallographic analysis

Metallographs were used to determine the degradation of the backsheet material. In Table 2, dark spots can be seen on Sample 1 (PVF/PET/PVF) after prolonged UV exposure to 330kWh/m$^2$. In addition, some white powder was observed on the PVF surface after 330kWh/m$^2$ of UV exposure, as shown in Fig. 6, which indicates that the material had begun to degrade.

A Fourier transform infrared (FTIR) measurement was also performed; the spectrogram is shown in Fig. 7. As speculated, it is observed that the FTIR spectrum of PVF changed after 330kWh/m$^2$ of UV exposure.

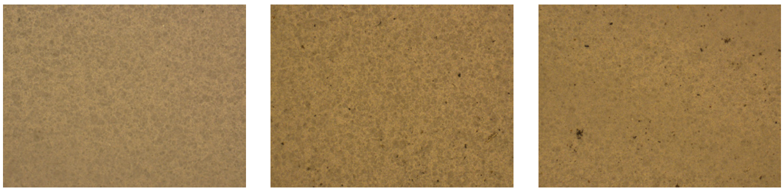
Sample 2 (PVDF/PET/PVDF) did not show any obvious change on the metallographs or in the FTIR spectrum (Fig. 8); when used as the inner layer, PVDF is therefore expected to provide more stable UV resistance than PVF.

Surprisingly, Samples 3 and 4 demonstrated high UV resistance because of the high UV resistance PE used by the supplier as the inner layer; however, these backsheets began to show evidence of slight cracking after 330kWh/m$^2$ UV exposure (Table 2).

The PET-based backsheet Samples 10

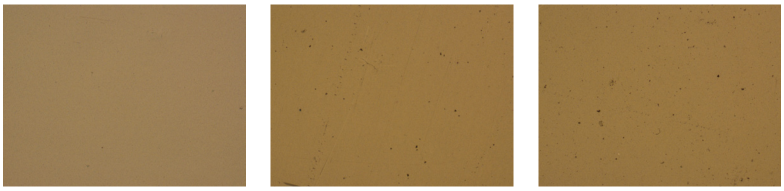
**Sample 1 PVF/PET(<36h)/PVF**

Initial | 120kWh/m$^2$ UV exposure | 330kWh/m$^2$ UV exposure



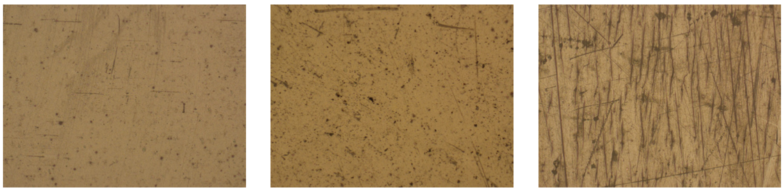
**Sample 2 PVDF/PET(48h)/PVDF**

Initial | 120kWh/m$^2$ UV exposure | 330kWh/m$^2$ UV exposure



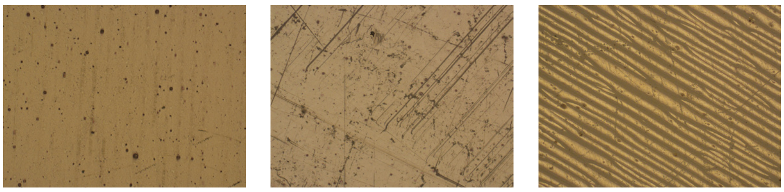
**Sample 3 PVF/PET(60h)/PE and Sample 4 PVF/PET(48h)/PE***

Initial | 120kWh/m$^2$ UV exposure | 330kWh/m$^2$ UV exposure



**Sample 5 PVDF/PET(48h)/PE**

Initial | 60kWh/m$^2$ UV exposure | 120kWh/m$^2$ UV exposure



**Sample 6 PVDF/PET(36h)/PE**

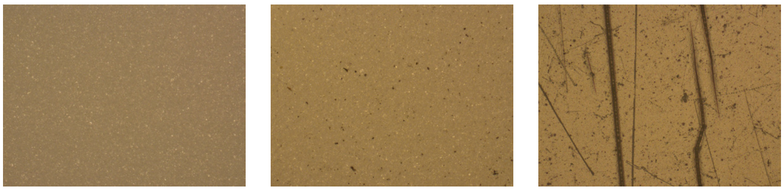
Initial | 60kWh/m$^2$ UV exposure | 120kWh/m$^2$ UV exposure

* Since Samples 3 and 4 are from the same supplier and use the same PE for the inner layer, only the metallographs for Sample 3 are shown.

**Table 2. Metallographs of the backsheets after prolonged UV exposure (Samples 1–6).**

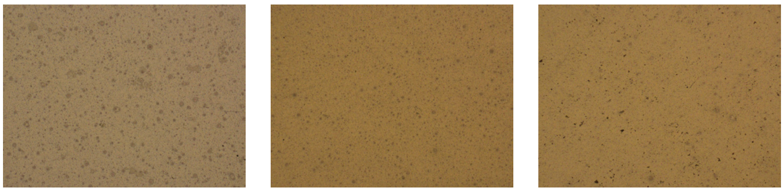
**Sample 7 ETFE/PET(<36h)/PE**

Initial | 120kWh/$m^2$ UV exposure | 180kWh/$m^2$ UV exposure



**Sample 8 PVDF/PET(48h)/Fluorine coating**

Initial | 60kWh/$m^2$ UV exposure | 120kWh/$m^2$ UV exposure

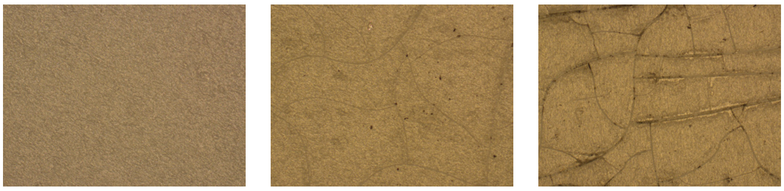


**Sample 9 Fluorine coating /PET(46h)/Fluorine coating**

Initial | 60kWh/$m^2$ UV exposure | 120kWh/$m^2$ UV exposure

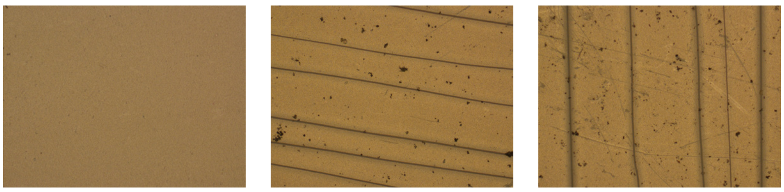
**Sample 10 Non-fluorine coating /PET(48h)/PP**

Initial | 45kWh/$m^2$ UV exposure | 120kWh/$m^2$ UV exposure



**Sample 11 PET/PET(60h)/PE**

Initial | 45kWh/$m^2$ UV exposure | 120kWh/$m^2$ UV exposure



**Sample 12 PA/PA/PA**

Initial | 120kWh/$m^2$ UV exposure | 180kWh/$m^2$ UV exposure

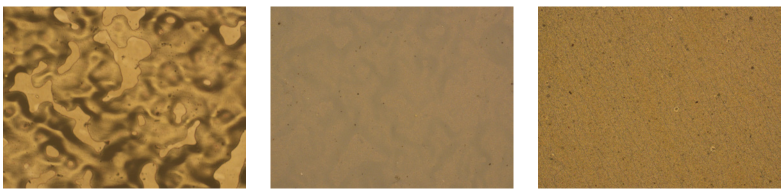


**Table 3. Metallographs of the backsheets after prolonged UV exposure (Samples 7–12).**

and 11 showed the worst UV resistance performance: they were only able to withstand 45kWh/$m^2$ of UV exposure, with obvious cracking observed.

Cracking was also evident with Sample 12 (PA/PA/PA) after 180kWh/$m^2$ of UV exposure. However, from the metallographs it was observed that the surface appearance of the inner layer of this backsheet began to change after 120kWh/$m^2$ UV exposure, which indicates that the material had already started to degrade.

The results of WVTR measurements for the backsheets before and after 120kWh/$m^2$ of UV exposure are shown in Fig. 9. It can be seen that the WVTR values for the backsheets that suffered cracking (Samples 5, 6 and 11) after 120kWh/$m^2$ of UV exposure are higher than their initial values. (Note that the measurement of WVTR for Sample 10 could not be performed, because of severe cracking of the backsheet.)

> “The PVDF film was found to have outstanding UV resistance performance, and even better than PVF film.”

From the results presented above, it is clear that the UV resistance performance of backsheets is mainly determined by the composition of the materials used. With material containing fluorine as the inner layer, excellent UV resistance is demonstrated; likewise, the use of a modified PE material as the inner layer can also provide a high UV resistance. The PET-based backsheets showed poor UV resistance, whereas the PA/PA/PA backsheet demonstrated a medium level of UV resistance.

## Conclusions

Several backsheets of various compositions and constructions have been put through extended accelerated ageing tests. The critical performance parameters – such as elongation, colour, surface appearance and WVTR – were evaluated and compared with a baseline PVF/PET/PVF backsheet, which has proven long-term reliability in the field.

The results show that the humidity performance of a backsheet is mainly affected by the hydrolysis resistance performance of the core layer PET material, and is not affected by the outer layer material. In damp-heat testing, the baseline PVF/PET/PVF does not yield satisfactory results owing to the low hydrolysis resistance PET. Apart from the PA/PA/PA backsheet, all the backsheets using PET with a high

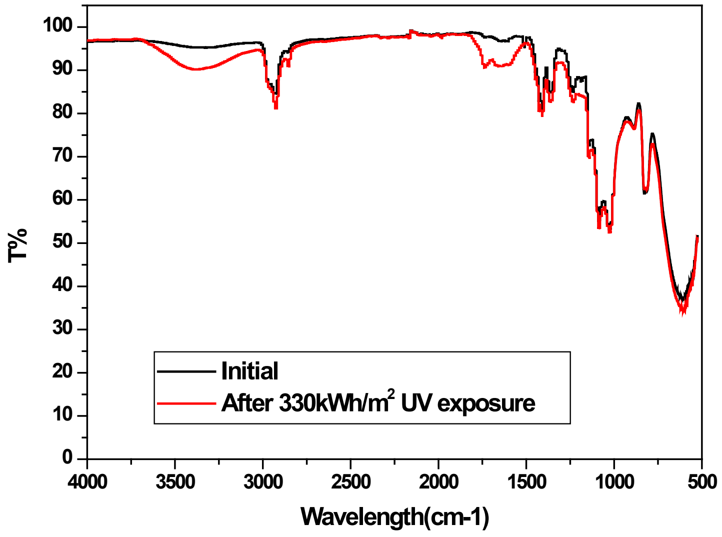



Figure 7. FTIR spectrum of PVF film used as the inner backsheet layer.

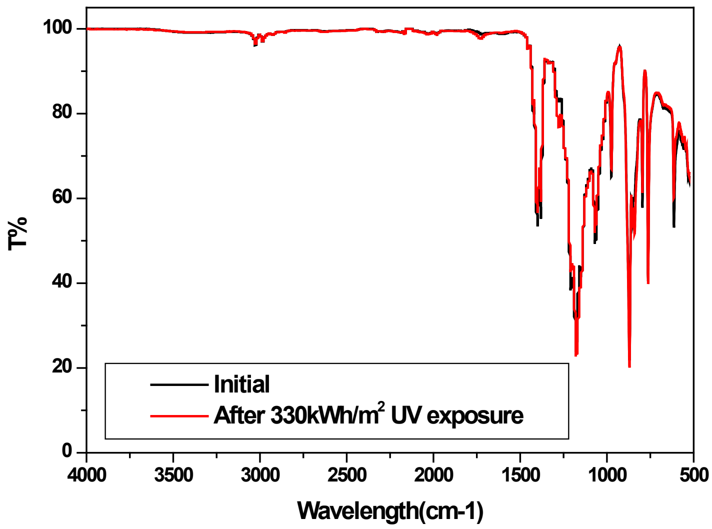



Figure 8. FTIR spectrum of PVDF film used as the inner backsheet layer.

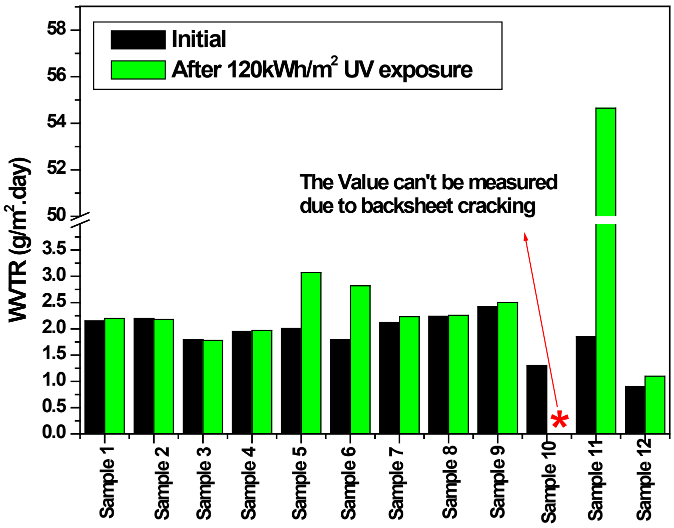



Figure 9. WVTR measurements for the backsheets after 120kWh/m² of UV exposure.

hydrolysis resistance (PCT 48h and PCT 60h) as the core layer demonstrate that they are better able to withstand exposure to humidity.

Humidity–freeze and thermal-cycling test results indicate that the weatherability performance is mainly influenced by the composition of the backsheet material; only the PA/PA/PA backsheet demonstrated poor weatherability performance.

The UV resistance performance of a backsheet is mainly determined by its composition and construction. The use of fluorine-containing materials offers excellent UV resistance performance. The PVDF film was found to have outstanding UV resistance performance, and even better than PVF film. When a modified PE is used as the inner layer of PVF-based and PVDF-based backsheets, the performance is also excellent in terms of UV resistance. In contrast, the UV resistance performance of the PET-based backsheet is poor, whereas that of the PA/PA/PA backsheet is only medium.



## References


[1] Skoczek, A., Sample, T. & Dunlop, E. 2009, "The results of performance measurements of field-aged crystalline silicon photovoltaic modules", *Prog. Photovoltaics Res. Appl.*, Vol. 17, p. 227.

[2] IEC 61215:2005, "Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval".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