Influences of different backsheets on PV module durability in high-humidity environments

Module durability | Different types of PV backsheet provide modules with varying levels of protection in warm, humid conditions. Haidan Gong, Minge Gao and Yiwei of Wuxi Suntech's PV test centre detail the results of research undertaken to better understand the properties of different backsheet materials in tropical conditions

As the most commonly used encapsulating materials, ethylene-vinyl acetate (EVA) and polymer backsheets play important roles in module performance by providing protection against environmental exposure. Although cured, EVA will still undergo hydrolysis when exposed to heat and moisture, leading to formation of acetic acid. The failure mechanism of modules under damp-heat conditions has been studied in other literatures [1, 2] [1, 2]. The acetic acid reacted with lead oxide and formed lead acetate, which can cause power degradation of the module. Most polymer backsheets cannot completely block the water ingress into the module. Therefore, the water vapor transmission rate (WVTR) of the backsheet is crucial to the module power degradation in a high-humidity environment. In the past, there were two different points of view. One was that a backsheet with a low WVTR should be used to obstruct moisture ingress as much as possible to inhibit the hydrolysis reaction of EVA. Another was that a breathable backsheet was preferable, meaning that the water can easily ingress into the backsheet but also that the acetic-acid gas also can easily release from the module.

At present, there is no definite conclusion about the WVTR selection of backsheets in tropical areas. Most research has focused on the durability of the backsheet itself and payed little attention to the influences of the backsheet's water barrier properties on module durability. In this work, three aspects are discussed: module performance using backsheet with different WVTR, module performance using EVA with different VA contents and correlation between damp heat accelerated ageing and applications in high-humidity environments.

Experiment section

Four types of commercialised backsheet were used including: glass (backsheet 1), KPO (backsheet 2), CPC (backsheet 3) and PPf (backsheet 4). Silicon-based PV modules incorporating these four different backsheets were produced, using the same manufacturing process. One special module without a backsheet was also produced. Initial stabilisation was undertaken and then modules were exposed to 85°C ambient temperature and 85% relative humidity as described in the IEC 61215 standard. Every 1,000 hours, the electrical performance of modules was tested.

EVA with two different VA contents (28% and 32%) were used. VA content was measured using chemical titration method with NaOH. The FTIR spectra were measured using a Thermal Fisher Nicolet iS50 equipment.

Results and discussion

Module performance using backsheet with different WVTR

External influences such as water and oxygen normally can penetrate a backsheet and go into modules as shown in Figure 1. As mentioned before, moisture in the modules can lead to cell corrosion. So, the water vapor transmission property of backsheet is crucial to module reliability and durability.

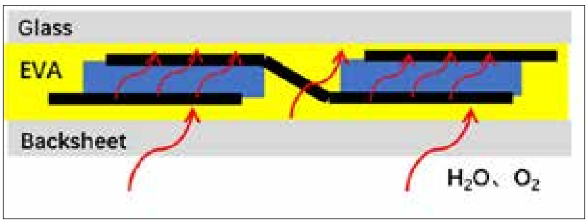


Figure 1: Water and oxygen penetration into module

	A	B	C	D	E
WVTR (g/m2•d)	0 (glass)	1.25	2.34	3.30	∞ (no backsheet)

Table 1: Modules using backsheets with different WVTR

Here, five groups of modules were produced under the same conditions (as shown in Table 1). Groups A to D used four types of backsheet with different WVTR and Group E were special modules without backsheets, meaning that the water vapor could totally ingress into the backsheet and the acetic-acid gas also could easily release from the modules.

These modules went through damp heat ageing for up to 4,000 hours and the module power loss was shown in Figure 2. It is clear that with increasing damp-heat time, modules using different backsheets showed different power losses. After DH 4,000h, modules using backsheet WVTR in the range of 0-4.0 g/m2•d (Group A to Group D), the power degradation increased linearly with increasing WVTR in a humid environment (as shown in Figure 3). The modules completely blocking water (backsheet A) showed limited power loss because these modules prevent the cell corrosion from acetic acid. The EL pictures after damp heat ageing are also shown in Table 2. The cell and ribbon corrosion conditions correspond to the power loss.

Interestingly, the modules without backsheet (Group E) showed low power degradation, and almost no cell or ribbon corrosion could be observed after 3,000h DH testing. But those modules showed large power degradation and obvious cell and ribbon corrosion after 4,000h DH testing. For modules without backsheet, in the first 3,000 hours of DH testing, the hydrolysis reaction of the EVA mainly occurred on the rear side of the module; the acetic-acid gas could also easily release from the module. But in the last 1,000 hours of DH testing, the water vapor penetrated

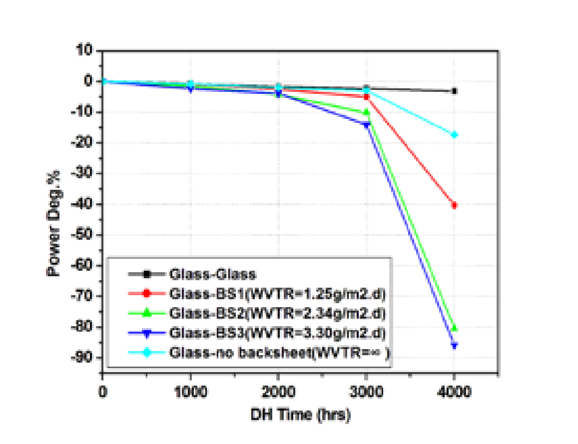


Figure 2. Power loss of modules different backsheets after DH

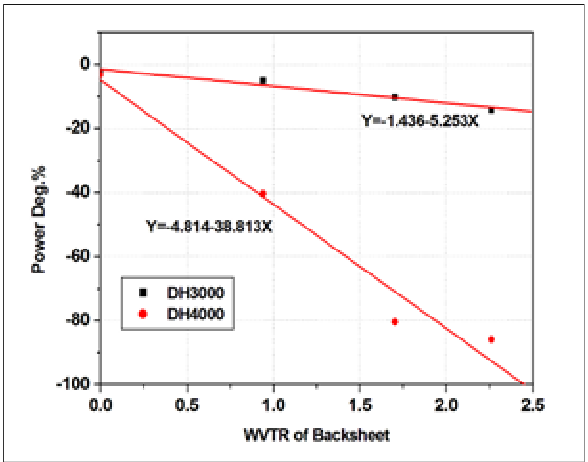


Figure 3. Power degradation vs. WVTR of backsheet

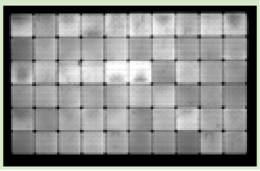
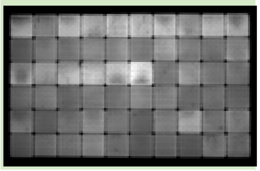
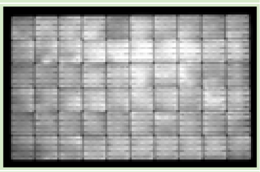
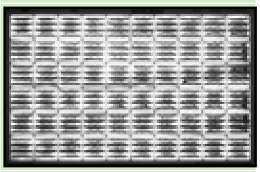
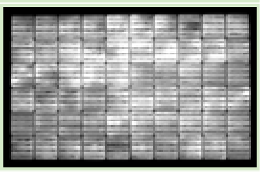
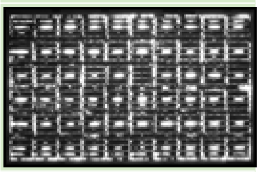
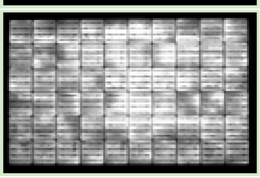
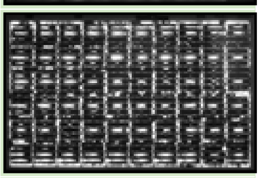
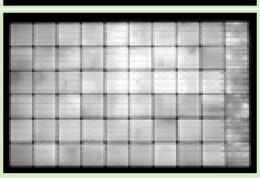
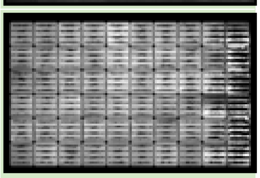
Group	After DH3000	After DH4000
A		
B		
C		
D		
E		

Table 2: EL pictures of modules with different backsheets after DH

the cell and ingressed into front side of the module, hydrolysis reaction of front side EVA is inevitable and the acetic-acid gas can't easily release through the cell.

Module performance using EVA with different VA content

The VA content is also a key value which affects the quality of EVA. In addition, the ester group will hydrolyse in a humid environment. EVA with 28% and 32% VA content were used in modules to see how they would perform in a humid environment. As shown in Figure 4, after DH 2,000h, modules using high VA-content EVA showed higher power degradation and more severe cell and ribbon corrosion. In Figure 5, modules with a higher VA content showed more cell corrosion after damp heat. This result corresponds to the power degradation results in Figure 4.

Correlation between damp heat accelerated ageing and applications in high humidity environment

In the natural environment, temperature, humidity and light are the three main factors that affect the reliability and durability of modules.

In order to predict a product's lifetime in real applications, several accelerated ageing models have been created and the Arrhenius model is the most known. In a high humidity environment, temperature and humidity play the major role in module ageing. Combining temperature and humidity factors, the Hallberg-Peck model[3] is commonly used to predict the ageing process in a high-humidity environment. The Hallberg-Peck model equation is as follows:

$$AF = \left(\frac{RH_t}{RH_u}\right)^3 \times e^{\left(\frac{E_a}{K}\right)\times\left(\frac{1}{T_u}-\frac{1}{T_t}\right)} \ldots\ldots\ldots eq1$$

T_u -1/T_t))………eq1

AF: accelerated factor

Ea: activation energy of this failure mode

K: boltzmann constant

Tu: absolute temperature under usage

Tt: absolute temperature under test

RHu: relative humidity under usage

RHt: relative humidity under test

Exceeded ageing time = Desired lifetime/ AF ...eq2

In the Hallberg-Peck model, the exceeded ageing time is related to the temperatrue and humidity in the application area as well as the activation energy of the modules' failure mode. The activation energy of the modules' failure is a the key parameter in

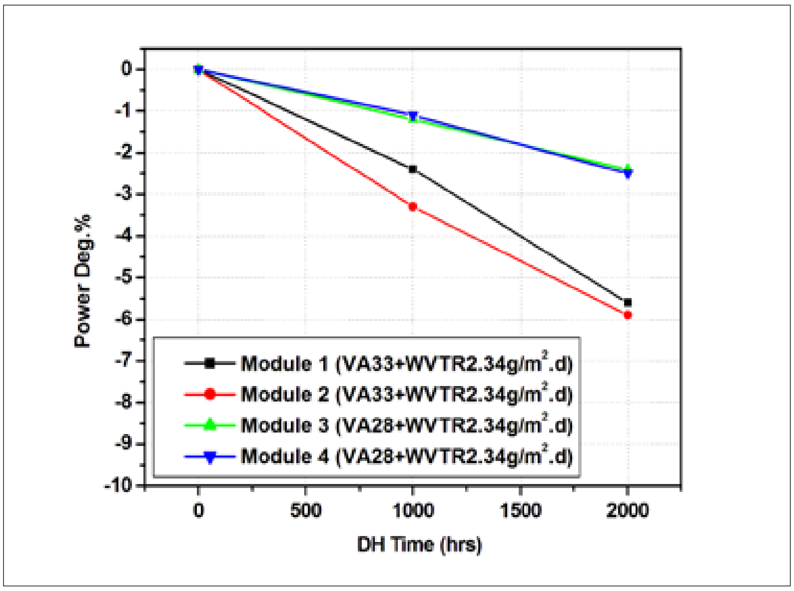


Figure 4. Power loss of modules using different EVA after DH testing

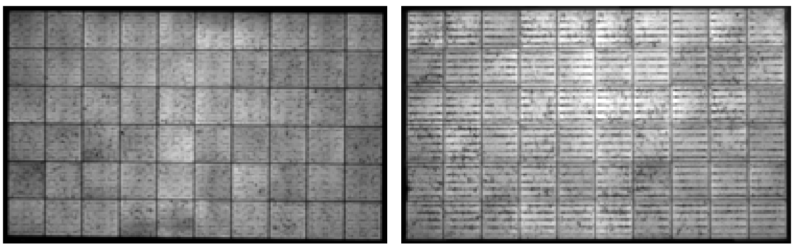


Figure 5. EL pictures of modules using different EVA after DH testing

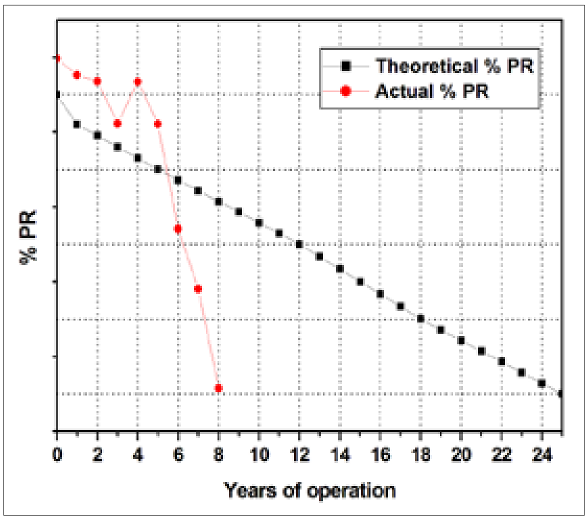


Figure 6. Actual PR degradation case installed in Southeast Asia

this model and usually it is an empiric value. Three real cases were studied to obtain the activation energy of this failure mode.

Case 1: modules installed in Southeast Asia in March 2012; average environmental temperature, 28.2°C, and average relative humidity, 61.8%. As shown in Figure 6, after only eight years operation, the PR of the whole PV plant show a high level of degradatio0n, close the theoretical degradation over 25 years.

Four modules were taken from the PV plant to measure the power output under a Class AAA pulse solar simulator. The results are shown in Table 3. It can be observed that the average power degradation of the modules encapsulated with BS WVTR 1.5 + VA33 EVA after eight years' operation is 28.5% and the average power degradation of the modules encapsulated with BS WVTR 1.5 + VA28 is 20%. We also took four modules from the warehouse, with the same encapsulation material and same production period (W32, 2011) as the modules from the PV plant, to receive 2,000h of damp heat testing. The results are shown in Table 4. It can be observed that there is a good correlation between 2,000h damp heat accelerated ageing and eight years of operation in a Southeast Asian tropical environment. The average power degradation of the modules encapsulated with BS WVTR 1.5 + VA33 EVA after 2,000h of damp heat testing is 26% and the average power degradation of the modules encapsulated with BS WVTR 1.5 + VA28 is 16%.

The electroluminescence (EL) after DH 2,000h showed similar appearances to the EL of modules aged in the Southeast Asian PV plant for eight years (Figure 7). Furthermore, Fourier-transform infrared spectroscopy (FTIR) was also applied to analyse the failure mechanism of the modules installed in the Southeast Asian PV plant and the modules after damp heat test (Figure 8). It was found that these modules have similar failure mechanisms. Lead acetate can be detected on the front side EVA. It is commonly believed that water vapor will penetrate into modules and lead to EVA hydrolysis. The resulting acetic acid will react with lead oxide in ribbons and cells. The formed lead acetate will cause resistance increases and cell darkening in EL. The difference is, lead acetate and peak EVA hydrolysis can't be detected on the rear side EVA in a failed module in the field. However, lead acetate and peak EVA hydrolysis can be detected on the rear side EVA of the module after damp heat testing. This result showed that the water vapor can ingress into the rear side of the module but also can diffuse to the outside through the backsheet in the field because the moisture concentration is different between inside and outside the module during day and night. When the water vapor penetrates a cell and ingresses into the front side of the module and can't easily diffuse through the cell, a hydrolysis reaction in front side EVA occurs. However, for the indoor ageing test, the water vapor will reach equilibrium both inside and outside the module during the whole ageing test, so the hydrolysis reaction of rear side EVA is inevitable.

Power degradation value, the EL images and FTIR showed that the indoor 2,000hrs of damp heat testing is equivalent to eight years operation in Thailand area. So according to the eq2, the AF is 35.04.

Case 2: modules installed on tropical Island A in 2012; average environmental temperature, 26.9°, and average relative humidity, 78.5%. As shown in Figure 9, only after six years' operation, the actual yield of electrical energy has 21.9% loss. In the EL image shown in Figure 10, cell corrosion also can be observed. Those modules are encapsulated with the BS WVTR 1.5 + VA33 EVA and BS WVTR 1.5 + VA28 EVA. According to Table 5, there is a good correlation between 2,000hrs damp heat accelerated ageing and six years of operation in the Island A environment. So according to the eq2, the AF is 26.28.

Case 3: modules installed on troprical Island B in 2013; average environmental temperature, is 27.2°C, and average relative humidity, 81.7%. As shown in Table 6, only after four years of operation, the actual yield of electrical energy shows a 17.6% loss. In the EL image shown in Figure 11, cell corrosion also can be observed. Those modules are encapsulated with the BS WVTR 1.5 and VA28 EVA. According to Table 4, there is a good correlation between the 2,000 hours of damp heat accelerated ageing and four years' operation in the Island B environment. So according to the eq2, the AF is 17.52.

Accoring to these three real cases, we can calculate the failure activation energy (Ea) of the failure mode in tropical areas; the related data are listed in Table 7. The Ea is about 0.425 to 0.482. Then we can use this

No.#	Pmax@initial	Pmax@after 8years	Deg.%	Material
1	294.2	200.9	32%	BS WVTR 1.5 + VA33 EVA
2	287.5	214.4	25%	
Avg. Deg.%			28.5%	
3	290.1	256.6	12%	BS WVTR 1.5 + VA28 EVA
4	291.3	209.9	28%	
Avg. Deg.%			20%	

Table 3. Power output of modules from Southeast Asia PV plant under class AAA pulse solar simulator

No.#	Pmax@initial	Pmax@DH1000	Pmax@DH2000	Deg.%@DH2000	Material
1	280.9	276.1	205.8	27%	BS WVTR 1.5 + VA33 EVA
2	278.5	277.0	208.1	25%	
Avg. Deg.%				26%	
3	213.6	206.4	188.4	12%	BS WVTR 1.5 + VA28 EVA
4	213.5	209.5	170.7	20%	
Avg. Deg.%				16%	

Table 4. Power output of modules from warehouse under class AAA pulse solar simulator

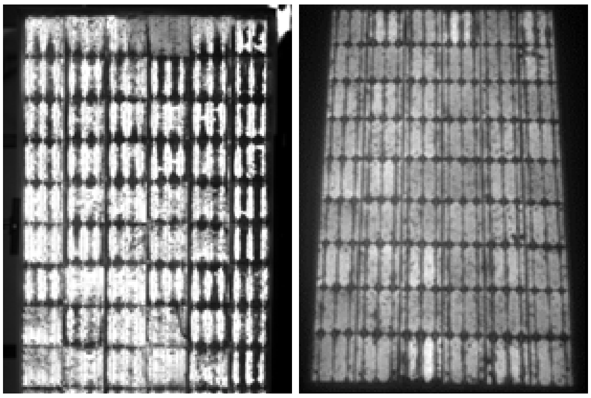


Figure 7. Left: module after installation in a high-humidity area for eight years; right: module after DH 2,000 hours

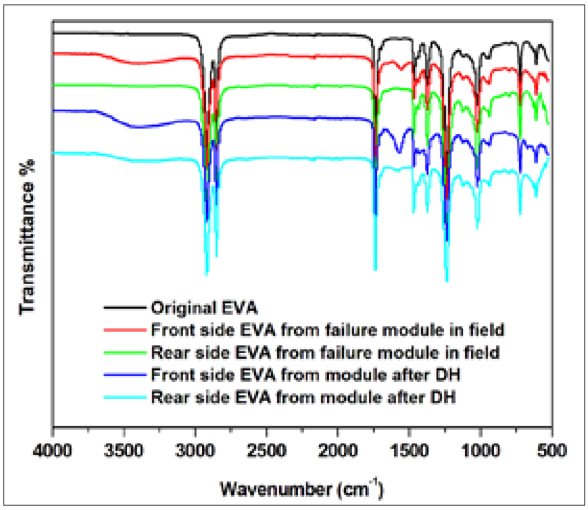


Figure 8. FTIR spectra of EVA from modules in field and after DH

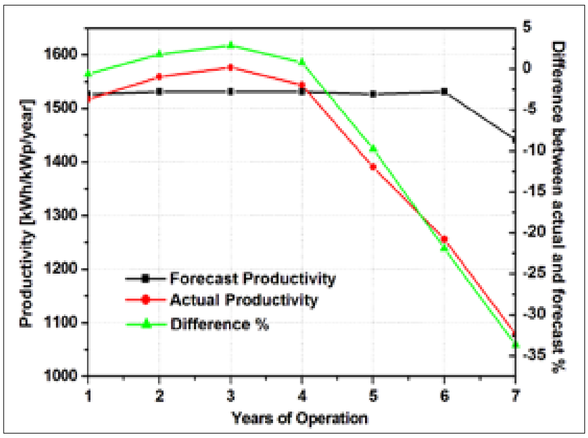


Figure 9. Actual PR degradation of modules installed on Island A

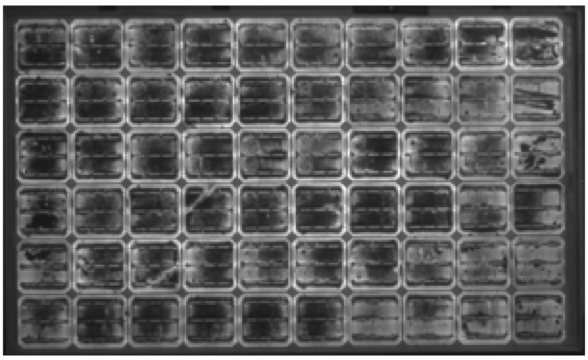


Figure 10. Module after installation on Island A for six years

No.#	Pmax@initial	Pmax@after 6years	Deg.%	Material
1	245.8	178.2	27%	BS WVTR 1.5 + VA33 EVA
2	240.0	207.0	13.8%	BS WVTR 1.5 + VA28 EVA

Table 5. Power output of modules from Island A PV plant under class AAA pulse solar simulator

	2013	2014	2015	2016
Yield (KWh)	85	85	75	**70**
% Yield Loss			11.8%	**17.6%**

Table 6. Actual yield of electrical energy from modules on Island B

	Avg. Temperature (°C)	Avg. Relative humidity (%)	AF	Calculated Ea (eV)
Southeast Asia solar plant	28.2	61.8	35.04	**0.425**
Island A solar plant	26.9	78.5	26.28	**0.482**
Island B solar plant	27.2	81.7	17.52	**0.440**

Table 7: The failure activation energy in tropical areas

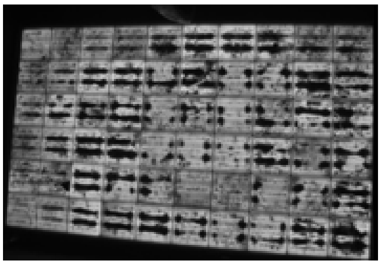


Figure 11. Module after installation on tropical Island B for four years

Ea and Hallberg-Peck model to calculate the different indoor extended damp heat testing time at different temperature and relative humidity area.

Conclusion

This work mainly focuses on the influence of backsheet WVTR on module performance in high-humidity environments. Theoretical modelling and field case data showed that long time damp heat accelerated ageing can simulate the module ageing pattern in a high-humidity field environment. Using the Hallberg-Peck model, the activation energy was calculated in areas with different temperatures and relative humidity. In addition, results showed that modules using backsheet WVTR in the range of 0-4.0 g/m2•d, the power degradation increased linearly with increasing backsheet WVTR in a humid environment. Finally, module performance using VA content 28% and 32% were compared. It was found that high VA content EVA will lead to higher power degradation and cell corrosion. ■

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