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Impact of Damp Heat and Ultraviolet Radiation on Common Solar Module Encapsulant Materials

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Abstract

PV technology is part of a burgeoning industry in renewable energy. Australia is a prime candidate for PV with high insolation levels. An investigation into the degradation of solar modules, of different construction, is important to understanding the prominent degradation pathways and the long term degradation properties of modules as they are exposed to the harsh Australian climate. Also, characterising the reliability of such materials will give an indication of module output in the future, leading to better output prediction. Although any prediction has challenges in being translated to actual field performance. In this paper, the impact of 2 significant degradation mechanisms (damp heat and UV) are detailed and profiled with respect to several common photovoltaic module materials. The degradation conditions were performed in accordance with IEC61215. Several manufacturers were considered and the extent of EVA browning, cell delamination, solar cell cracking and power loss were recorded. Of the materials tested, DH was found to impact the adhesion of the EVA-glass layer more than UV and changed the failure mechanism to the outer layer of backsheet. The optics of the samples were effected by moisture ingress generally lowering transmission.

1. Introduction

PV technologies have been the subject of increasing public and research interest especially in recent years as the costs have fallen significantly. PV has high potential as an alternative utility scale power generator to current fossil fuel based generators but the future of PV needs accurate prediction of lifetime system output to become further economical and practical. Two main cost drivers for PV are the efficiency with which sunlight is converted into power and how this relationship degrades over time (Jordan and Kurtz, 2011). This relationship is of vital importance to the growth of the PV industry. Degradation studies are also important to characterise in Australia due to the unique atmospheric effects such as increased UV dosage. Early installations of solar modules (20-30 years) are reaching their end of life and so the time frame to determine and publish long term reliability tests is only recently come into being. An analytical review of 2000 published degradation rates of c-Si from the last 20 years was detailed in Jordan, D. and Kurtz, S (2011). A summary of accelerated degradation tests from 1975-2008 in Osterwald (2009).

Discoloration of EVA, known as EVA browning, is a common loss mechanism due to the reduced light transmittance though to the solar cell. Different factors that affect EVA browning were published in Pern (1996). EVA can accumulate water vapour during long term exposure. The study of moisture ingress is shown in Kempe (2005).

McIntosh (2010) measures the degradation of several encapsulant materials encapsulated in quartz but did not extend to all solar cell encapsulating materials. The experiment conditions and durations under which the samples were exposed were an indication to this project for the timeframes needed to adequately degrade the samples to reach significant results.

A model for optical losses has been developed involving ray trace simulation in McIntosh (2009). Ray tracing is not trivial as it involves plotting and analyzing an infinite number of reflection and transmission pathways between multiple materials. This method will be valuable to the project by providing a method for high accuracy analysis. In this paper a silicone based encapsulant is used rather than the more common EVA encapsulant. It was shown that the short circuit current density increased by 0.7-1.1% with silicone due to the increase of transmitted higher wavelength light.

1.1. Review of IEC 61215

IEC 61215 is a major performance evaluation standard for crystalline silicon (c-Si) solar modules. It details a several series of accelerated tests designed to assess safety and performance of a market ready solar module against common failure mechanisms such as delamination, cell and glass breakage, severed interconnects and deteriorated optics. In which these are achieved in part mimic the practical conditions of the module albeit highly exaggerated. Two tests were highlighted for the purpose of this report, Damp heat and UV preconditioning. Table 1 contains the details of these two tests.

Although thorough, an international standard cannot properly simulate the unique and variable conditions of a location based climate. Australia has one of the highest UV in the world and so special consideration of UV degradation is needed. The UV preconditioning test provides a rather low dosage of UV exposure to modules compared to the durations of other IEC 61215 tests let alone the dosage of a 20+ year lifetime (Kempe, 2008).

Table 1: IEC 61215 testing requirements for Damp Heat and UV preconditioning tests.

Test name	**Damp Heat (DH1000)**	**UV preconditioning**
Test duration	1000 hours	7 days[1]
Temperature	85°C ± 2°C	60°C ± 5°C
Relative humidity	85% ± 5%	N/A
Irradiance dosage	N/A	15 kWh/m^2 (280-400nm) 5kWh/m^2 (280-315nm)

1.2. Experimental

The chosen experiments were designed to profile the key degradation areas with different encapsulant materials under DH and UV, separately. They are in line with the standardised tests detailed in IEC 61215 with continued testing once they were met. 2 EVAs and 3 backsheet materials were used separately and laminated together in small scale versions of a module without solar cells. Double glass laminations were made to highlight the degradation of EVA alone. Laminated samples used a double bag vacuum laminator with a consistent lamination process to the manufacturer's specification of EVA curing time and temperature. Where possible samples were group laminated to eliminate potential temperature fluctuations. No edge sealing was applied.

1.2.1. Damp heat (DH1000)

Damp heat is an environmental test aimed at rapidly inducing the effects of water vapour and heightened temperatures. Samples were placed at 85°C and 85% relative humidity environment for the entire duration. Delamination and increased scattering of light due to the introduction of water into the sample are common methods of solar cell failure. These conditions were held for up to 2500 hours which meets IEC 61215 but longer durations have been used in Ketola and Norris (2011) which documents the dramatic module degradation effects for 7600 hours. *Green* 2.5mm glass was used in all laminations. A set of laminations using microscope slides (3x7cm) were created for spectrophotometer use and other larger set (20x20cm) was used for the end purpose of a peel test.

1.2.2. UV exposure

UV exposure is an irradiance test that simulates a high irradiance over a specific light spectrum at 60°C. The holding temperature is in the upper bound of cell temperature during practical applications. The UV portion is calculated and the dose of UV can be controlled. The high energy photons of the UV spectrum can cause damage to susceptible materials but IEC 61215 requires a relatively small dose of UV compared to the lifetime of the manufactured PV modules. The Q-Sun X-1 Zenon Test Chamber was used for the rapid UV exposure of the encapsulant materials. *Clear* 3.8mm glass was used on all laminated samples to minimize the deduction of UV dose to the encapsulant material. The UV spectrum profile of the selected filter. Due to the size of the test chamber the size of the UV samples was limited to 10x10cm which was convenient for spectrophotometry and to fit all samples in at once.

[1] Test duration is dependent on irradiance levels set by the accelerated UV test equipment. In this case the limiting factor is the light filter.

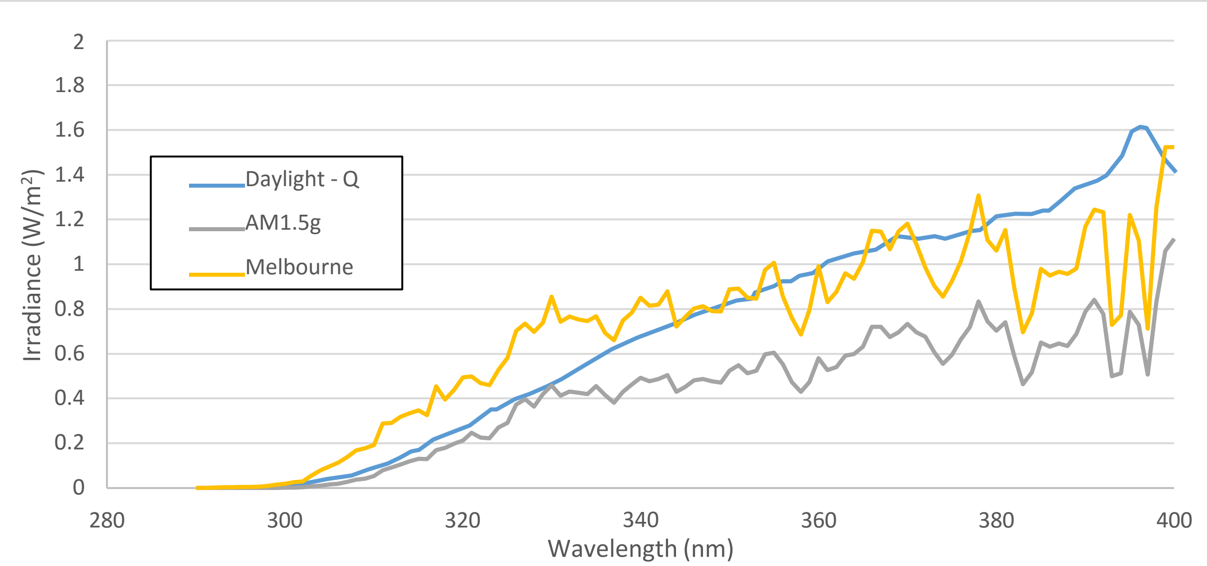

Figure 1: Comparison of UV spectrum for the Daylight - Q filter and modelled outdoor conditions

The Daylight – Q curve was integrated using the trapezoid rule to find the total UV dose as a function of time. Over the course of 8 weeks, the samples experienced 119 kWh/m2 of total UV.

2. Results and Discussion

All samples received either DH or UV dosage separately. Combined degradation was not performed due to the destructive nature of the peel test. Ongoing measurements of sample discolouration were made through photocopy scans while the spectrophotometer measurements were taken before and after. Spectrophotometry test were performed before the samples destruction in the peel test.

2.1. 90^0 Peel test

The peel test is a mechanical test used to determine the adhesion strength of the encapsulant layers to the glass, whether it's the EVA-glass, EVA-backsheet layer or an inner layer of the backsheet itself. As it is a destructive test it was performed only at the end of the samples degradation cycle when no more testing was needed. A 1cm wide strip of the encapsulant was cut along its length from the backsheet down to the glass and a tab was created for the machine to grip and pull from.

Figure 2: Sample made ready for the peel test (Left) and a sample held in the Instron during the peel test (Right)

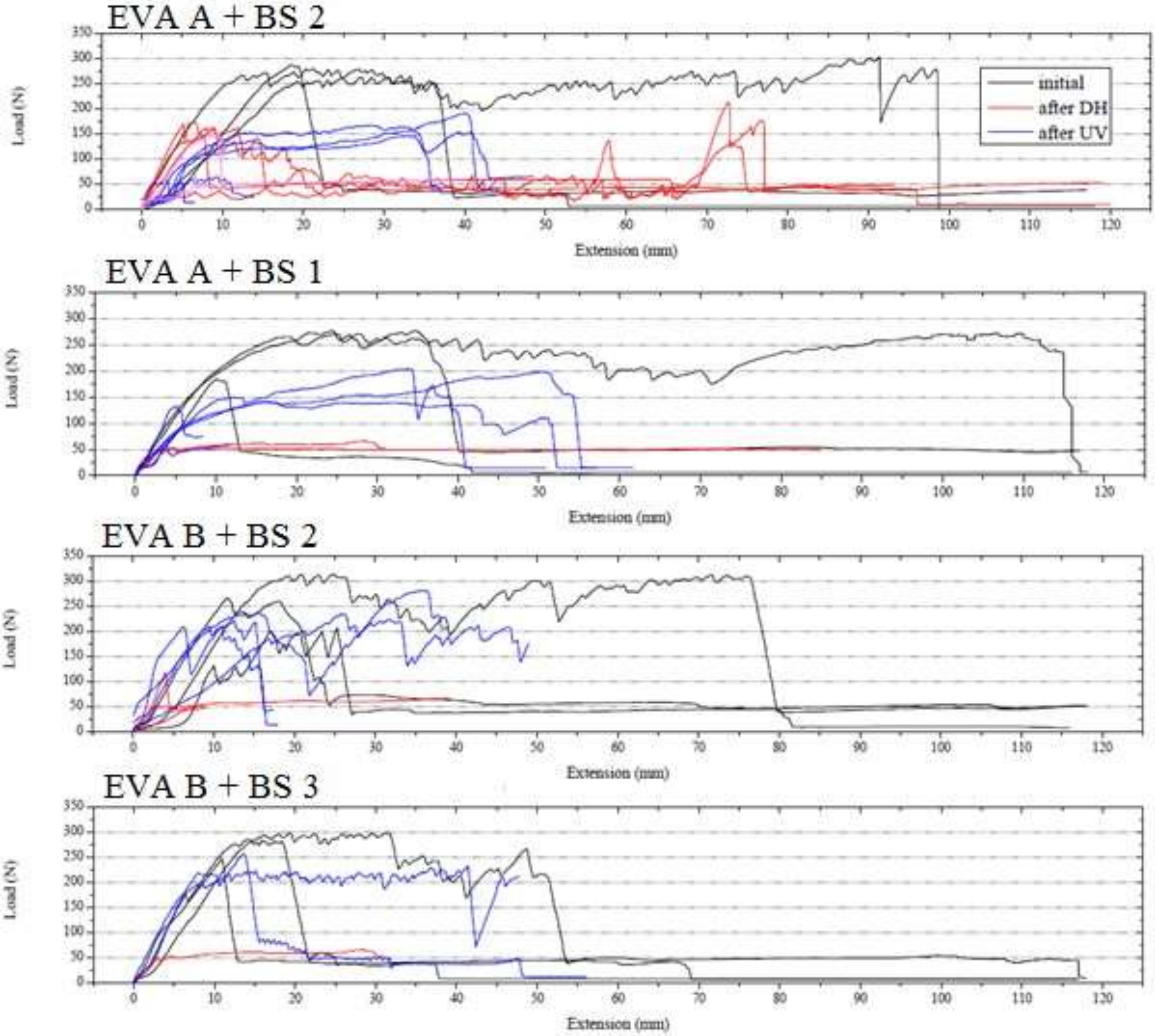

Figure 3: Peel tests for DH samples were exposed for 2600 hours and UV samples were exposed to 119 kWh/m^2 of UV (280 – 400nm). Loadings of ~50N experienced backsheet rupture and EVA stretching.

It is clear that not only have the maximum adhesion forces of the all samples lowered under both UV and DH. DH effected the longevity of the peel test as the outer layer of backsheet had become brittle and snapped immediately once in tension between 50 – 100N. This value is about a third of the expected EVA peel force that was experienced from the initial samples. Slow EVA peeling was observed once the backsheet had broken and the strip underwent elongation however this was much slower than the peel with the backsheet intact.

Areas of EVA-Backsheet delamination were visually evident on EVA A + BS 1 but due to strip breakage the impact of delamination on the load could not be seen.

EVA B + BS 3 was the strongest sample with a maximum peel strength of 300N/cm.

2.2. Spectrophotometer results

Where possible a spectrophotometer was used to characterise the optical changes before and after exposure. DH samples using microscope glass were exposed to 2500 hours while the UV samples were measured after 119 kWh/m^2 of total UV dosage. The optics of the different materials BS 3 was a black backsheet that absorbs most light rather than reflecting it like the other white backsheets, BS 1 and BS 2.

2.2.1. UV exposure

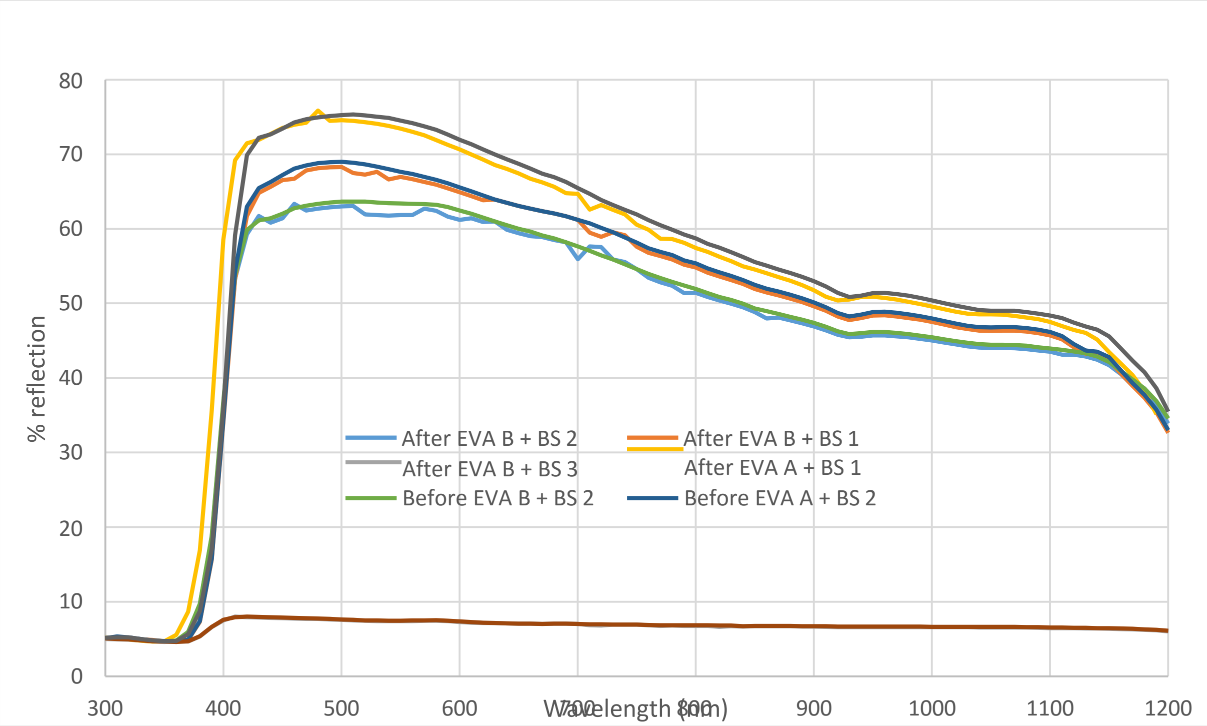

Figure 4: Spectrophotometry for UV degraded samples before and after 119 kWh/m^2 total UV dosage.

The final dosage was equivalent to 8x that of IEC 61215 and 2x higher than the same duration under fulltime AM1.5g or equivalent to 16 weeks of outdoor exposure (Bokria, 2013). No evidence of EVA browning or delamination were present. The extent of this experiment was not sufficient to produce dramatic change in the samples like the DH was able to do. The relatively low dosage compared to the estimated 25 year lifetime amount of 3000 kWh/m^2 or 4% (Dunn, 2013).

2.2.2. DH exposure

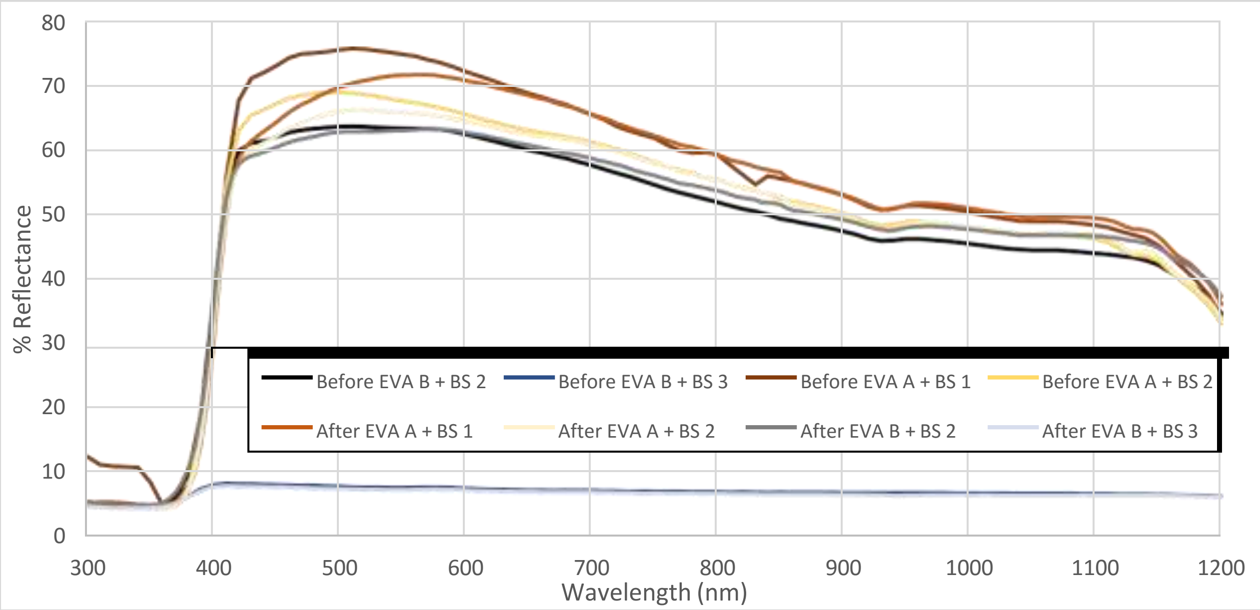

Figure 5: Spectrophotometry from 300-1200nm of DH samples after 2500hours of exposure

The DH had degraded most significantly in the visual spectrum of light with a 6% difference in reflection. It is suggested the ingress of moisture into the samples has scattered light and increased the absorptivity. The UV blocker appears to remain so far undamaged as the cutoff for wavelength was still around 420nm. Visually the EVA A +BS 1 sample was most severely discoloured with a distinct yellowness that is believed to be caused by the EVA primer on the surface of the backsheet. Double glass laminations showed increased delamination around the edge and reduced transparency due to hazing focused on their center.

3. Conclusion

A variety of common solar cell encapsulant materials were laminated (without a solar cell) and then degraded using 2 methods; Damp Heat and UV radiation as per the specifications of IEC 61215. Four samples featuring 5 encapsulant materials. The material characteristics were found to have altered primarily the adhesion of all samples was lower after degradation and the principle failure mechanism of the peel test was the now brittle backsheet outer layer

The 400- 900nm range was most heavily effected by DH for most samples while the UV dosage does not appear to be sufficient in degrading the samples significantly beyond a few percent of initial. A higher test duration is recommended for further analysis of the extent of UV degradation.

EVA B + BS 3 had the highest adhesion strength before and after UV degradation whilst the DH results were inconsistent with previous peel tests due to backsheet rupture.

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