

DEVELOPMENT OF ADHESIVE AND COHESIVE FAILURES IN EVA-BACKSHEET STRUCTURES IN ENVIRONMENTAL TESTING

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ABSTRACT: The development of adhesive and cohesive failures at the EVA-backsheet interface under different damp-heat (DH) testing condition is investigated in this paper. The adhesive and cohesive failures are classified by the surface roughness of the peeled off backsheet strips. Different DH testing condition leads to different dominating failure modes. The adhesive failure is the main failure mode at lower testing temperature, which has been masked by the mixed failure mode at the higher testing temperatures due to the different temperature acceleration factor of the two processes. Development of accelerated environmental testing protocol requires the failure mode analysis to ensure the target failure mode or degradation mechanism is accelerated and not masked by any other processes.

Keywords: adhesive, cohesive, EVA, backsheet, acceleration

1 INTRODUCTION

PV module packaging consists of front cover, encapsulant, backsheet and edge seal. This forms a multilayer system which results in a number of interfaces. Different interfaces as well as the bulk materials degrade during outdoor operation. Good adhesion between these interfaces is necessary to minimise contaminants ingress (and generation) that will further degrade modules and provide safety insurance. Backsheet delamination, as a result of loss of adhesion, is a commonly observed failure mode in PV modules. Loss of adhesion strength depends on operating conditions. Currently there are some minimum requirements being set for adhesion strength in as produced modules, but there is a missing foundation for these values, which is the identification of failure modes, i.e. the distinguish of adhesive and cohesive failures at any interfaces investigated.

Ethylene Vinyl Acetate (EVA) is still the most commonly used encapsulant in the PV industry. A complex cocktail of additives is used to enhance the performance of pure EVA resin. This may include adhesion promoter, normally in the form of silane-coupling agents that are used to enhance adhesion between EVA and glass by forming silicon-oxygen covalent bonds. For the adhesion between EVA and the backsheet, coupling agents or primers are often added at the inner side of the backsheet to enhance adhesion by either forming chemical bonds or increasing physical absorption. In order to test the performance and durability of the encapsulation materials, manufacturers rely on standardised environmental tests, e.g damp-heat (DH), thermal-cycling (TC), humidity-freeze (HF) and etc.

The environmental testing is designed as a screening test for specific ageing mechanisms. The tests have been adopted from other industries and there is the possibility of them giving misleading results. This is particular true if multiple degradation mechanisms exist with different thermal acceleration, i.e. different activation energy (E_a). Given that environmental tests are conducted at elevated temperature to gain some acceleration, this may result in skewed priorities in failure analysis. This paper investigates this phenomenon for two failure modes that are the adhesive and cohesive failures within EVA-backsheet structures observed during DH testing. At this interface, moisture ingress may cause bond

decomposition. This depends on the type of the bond, but will also result in reduced adhesion strength. Such a debonding reaction is normally accelerated by temperature. Backsheet material will also suffer from hydrolysis and become brittle upon moisture absorption which produces extra stresses within the interface. Those processes occurred at the same time. Either one of them might become a dominating process that leads to a specific failure mode depending on the environmental testing condition and the testing time.

2 EXPERIMENTAL SETUP

2.1 Testing samples

In order to test the adhesion failure at the EVA and backsheet interface, PV laminates with a backsheet/EVA/EVA/backsheet structure were laminated (Fig. 1a) at Centre for Renewable Energy Systems Technology (CREST) using a 2BG laminator L176A. The size of the samples is 20cm by 12.5cm (Fig. 1b).

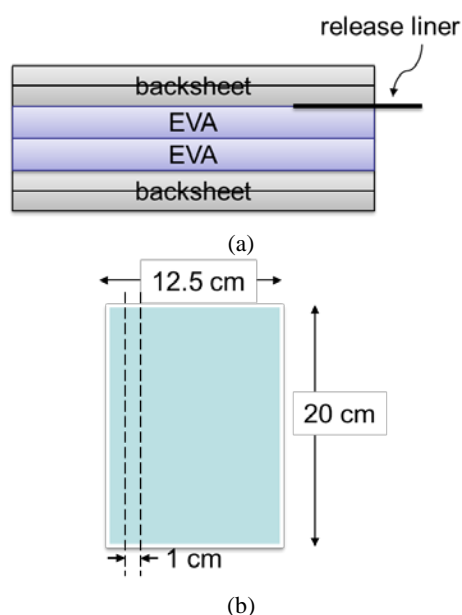


Figure 1: EVA-Backsheet PV laminates tested in this work a) structure and b) size of samples.

Table I: DH conditions and measurement intervals

Test name	Temperature (°C)	Relative humidity (%)	Test time intervals (hours)
60/85	60	85	0, 50, 100, 250, 500, 1000
85/85	85	85	0, 50, 100, 250, 500, 1000
95/85	95	85	0, 50, 100, 250, 500, 1000
120/100	120	Maximum (85-100)	0, 12, 24, 50, 100

The EVA is 460µm fast cure EVA with 34% of vinyl acetate. The backsheet is a two-layer insulating polymer consisting PET/primer layer. More typical tri-layer backsheet was not used which reduces the number of interfaces. A silicone coated release liner was inserted between backsheet and EVA at the very beginning of the samples (2 cm) to allow an easy removal of the combined PET-EVA layer to form the peeling tab.

2.2 T-peel test

Adhesion at EVA/backsheets interface was measured by conducting the T-Peel test with a Chatillon motorised force tester at CREST as shown in Fig. 2. Each testing sample was cut into strips of 10mm width for the peel test (Fig. 1b). The test was carried out at a constant crosshead speed of 50mm/min in room condition. A total of 15-20 stripes from two to three laminate samples were measured for each testing intervals from which the average adhesion strength and frequency of failure mode were calculated. Effects of the environment and peel speed on the peel strength values are not the scope of this paper as the focus is on the comparison study of the failure mode in the EVA/backsheets structures during the peel test.

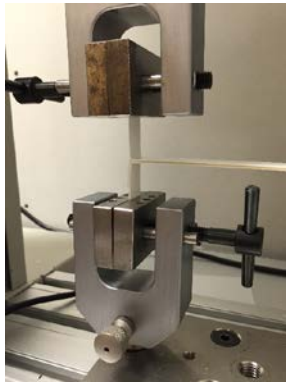


Figure 2: Setup of T-peel test.

2.3 Damp-heat test and measurement intervals

The damp-heat tests were carried out in environmental chambers at CREST. Four damp-heat conditions with temperature ranging from 60°C to 120°C implemented in this work are summarised in Table I. The test duration is 1000 hours except that it is 100 hours for the testing at 120°C/100%R.H. as the samples degraded quickly and became too brittle to peel at this stress condition. The measurement intervals are also defined in Table I. At the beginning of the DH tests, 10-12 laminate samples were loaded into the environmental chamber. At each measurement interval, 2-3 laminates were taken out for T-peel test in order to track the degradation process over ageing time.

3 DEVELOPMENT OF ADHESIVE AND COHESIVE FAILURES

3.1 Peel strength and failure types

Peel strength values are likely dependent on a number of factors including the peel angle, backing material, peel speed and etc. Typical peel strength measurements plotted as measured load (in Newton) against time are shown in Fig. 3. They are the measurements for all strips after 50 hours ageing at 85°C/85%R.H. The solid red line is the average of these measurements. Three spikes can be seen around 120s and 270s. These variations are difficult to avoid in peel strength measurements and they might be related to different failure types. In order to confirm whether a different failure mode was developed, surface analysis was carried out for the area A and B of the peeled off backsheets strips, respectively.

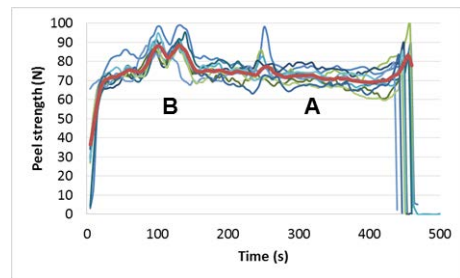


Figure 3: Peel strength measurements for samples after 50 hours DH at 85°C/85%RH. Position A is with relative flat peel strength values, whereas position B is with spikes in peel strength.

3.2 Surface analysis of peeled backsheets

As shown in Fig. 3, position A is with relative flat peel strength values, whereas position B is where the spikes occurred. Analysing the inner side surface of the peeled off backsheets strips for the two positions, clear differences were found.

Fig. 4 shows the microscopic images of the surface at position A and B, respectively. The surface of peeled off backsheets strips at position A is smooth, while the surface at position B is coarse. Furthermore, the surface roughness was also measured for the two positions by using the Coherence Scanning Interferometry (CSI). Multiple measurements were taken and part of the result of three dimensional surfaces was shown in Fig. 5. It is clear to see from the result that the surfaces at position B (Fig. 5a) have relatively bigger peaks and valleys, whereas the surfaces at position A (Fig. 5b) have relatively smaller peaks and valleys. One parameter used to describe the surface roughness is the averaged deviation of the surface height. The averaged deviation calculated for position A is 0.48-0.49µm, which is much lower than that at position B that varies between 0.8µm and 1.12µm.

With the surface analysis, the adhesive and cohesive

failures are defined and able to be distinguished. The failure at the position A and B are classified as adhesive and thin cohesive failures, respectively. It is likely that the different failure modes are due to the factors such as the variations in manufacturing process of the material, imperfect lamination quality due to uneven temperature and pressure distribution, and etc.

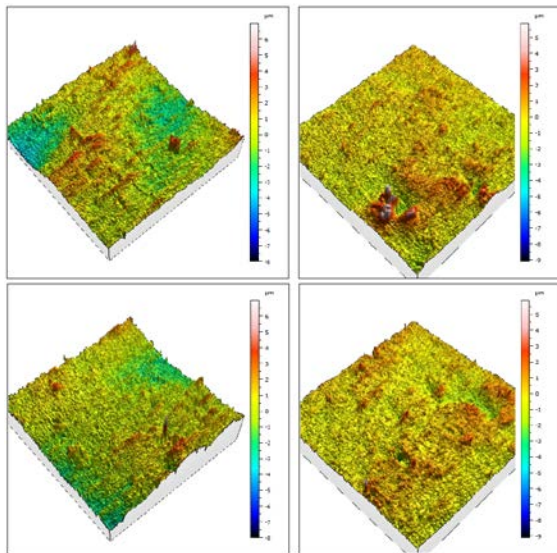


(a)



(b)

Figure 4: Microscopic images show the difference in backsheet surface where a) adhesive failure (position A in Fig. 3) and b) thin cohesive failure (position B in Fig. 3) occurred.



(a)

(b)

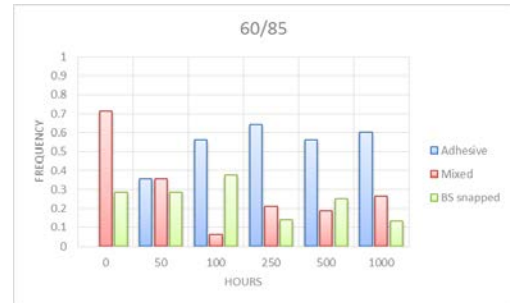
Figure 5: CSI measurements show difference in surface roughness of backsheet where a) thin cohesive (position B in Fig. 3) and b) adhesive failure (position A in Fig. 3) occurred.

4 FAILURE TYPES OVER AGEING TIMES

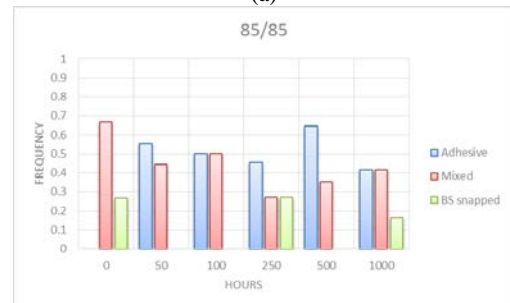
4.1 Observed failure types under different DH conditions

Applying the failure mode analysis for all the peeled off backsheet strips after ageing under different DH

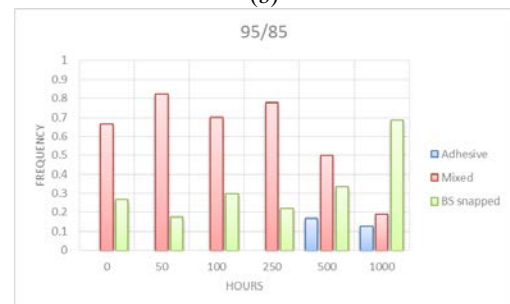
conditions, the frequencies of failure modes over ageing time are plotted in Fig. 6 and investigated. Three failure modes are defined in this investigation, including the adhesive failure mode, the mixed mode of adhesive and thin cohesive failures and the failure mode due to backsheet strips being snapped during the peel test.



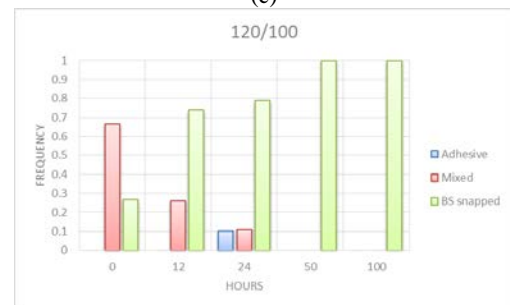
(a)



(b)



(c)



(d)

Figure 6: Frequencies of observed failure types over ageing time under different DH conditions at a) 60°C/85%R.H., b) 85°C/85%R.H., c) 95°C/85%R.H. and d) 120°C/100%R.H.

As clearly seen from Fig. 6, more adhesive failures were observed at the DH testing condition of 60°C/85%R.H. The frequency of mixed failure mode increased when testing at 85°C/85%R.H. Under the testing condition of 95°C/85%R.H., the mixed failure mode became dominating and about 2 out of 3 backsheet strips were snapped during peel test after 1000 hours

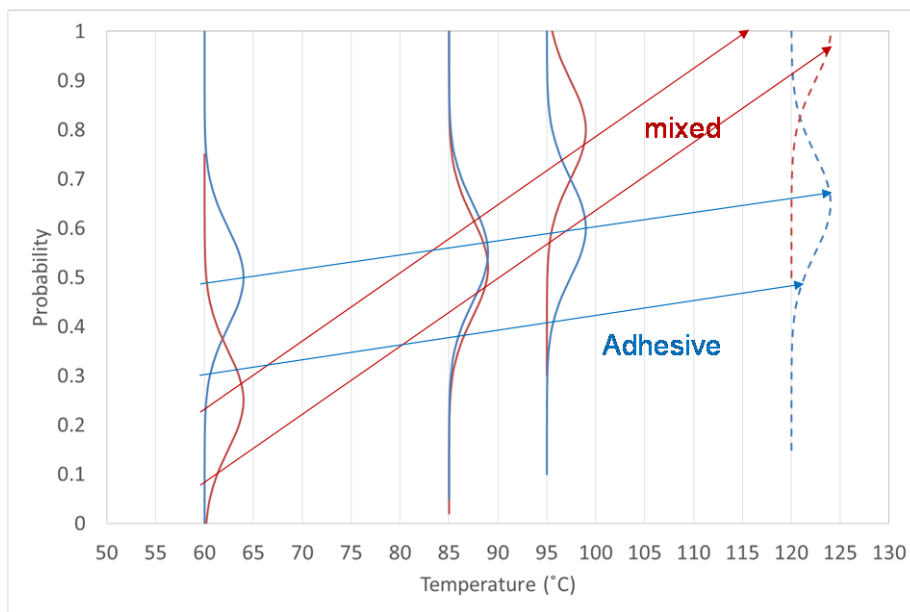


Figure 8: Probability analysis for adhesive and mixed types of failure for DH testing at 60°C, 85°C and 95°C.

testing. At the highest testing condition of 120°C/100%R.H., the samples degraded fast and became brittle due to the hydrolysis of backsheets. Thus, the embrittlement led to the failure of snapped backsheets as the main failure mode after 12 hours.

4.2 Probability analysis for failure mode analysis

A statistical approach of probability analysis for the adhesive and mixed failure modes was carried out in attempt to show the effect of temperature acceleration on the failure modes.

This approach adopts the Gaussian distribution to represent the probability of occurrences of a specific failure mode. As depicted in Fig. 7, the distribution of adhesive failure exhibits bigger probabilities than the distribution of mixed failure mode. This means at this testing condition, the samples are more likely to suffer the adhesive failure than the mixed failure. Both distributions might move towards higher probabilities if higher stresses or longer testing time is imposed upon the testing samples as heavily degraded samples are more likely to fail.

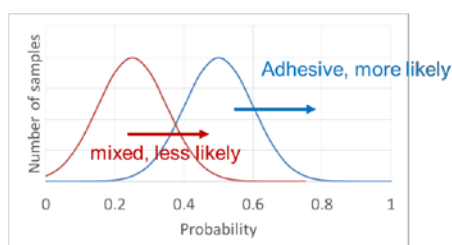


Figure 7: Probability analysis used for adhesive and mixed types of failure.

The probability analysis is applied to all the tested samples. Based on the observed failure modes as reported in Fig. 6, the distributions of the adhesive and mixed failure modes in dependency of testing temperature are shown in Fig. 8. The failure probabilities increase with the increasing testing temperature. This is due to the fact that temperature acts as an accelerator in both failure

modes. However, the acceleration factors due to temperature are not at the same level for the two failure modes. At 60°C, the samples are more likely to suffer adhesive failure, which is the main failure mode. At 85°C, the probabilities for the adhesive and the mixed failure are at a similar level which means there is no dominating failure mode. At 95°C, on the contrary, the mixed failure is more likely to happen and became the main failure mode. The potential reason behind this can be explained that the temperature acceleration for the mixed failure mode is with a relatively larger E_a , while that for the adhesive failure mode is with a relative smaller E_a . Therefore, the mixed failure process with a large E_a is accelerated significantly at higher temperatures and masks the process of adhesive failure with a smaller E_a . There is no measurement available to show the probabilities of adhesive and mixed failure mode at 120°C as all samples saw snapping backsheets strips, i.e. a third failure mode masks those two failures at 120°C.

Considering the outdoor PV module temperatures under different climates [] are normally up to 80°C, the tests carried out at temperature above this, e.g. the pressure cooker test (PCT), might lead to a different dominating failure mode and masks the realistic failure mode that is seen by fielded modules.

5 CONCLUSIONS

Failure mode analysis at the EVA/backsheet interface for PV laminates underwent DH testing at different temperature and relative humidity conditions are carried out. Different failure modes including the adhesive and thin cohesive failure are identified and the development of the adhesive and cohesive failure mode is found to be directly related to the DH testing condition. Lower testing temperature at 60°C leads to adhesive failure at EVA/backsheet interface, whereas the failure mode changes to the mixed failure at testing temperature above 85°C. Therefore, the development of accelerated testing protocol for PV modules or components requires the

comprehensive failure mode analysis for the tested samples in order to ensure the target failure mode or degradation mechanism is accelerated and not masked by other processes. Generally, testing at reasonable lower temperatures is more realistic though the acceleration factor might be small and the tests duration is relatively longer.

REFERENCES

- [1]
- [2]