# Degradation Study of the Peel Strength of Mini-Modules under Damp Heat Condition

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**Abstract** This paper presents the degradation study results of adhesion strength between backsheet and encapsulant for a commercial mini-module. A concept of environmental dose is established to quantify the cumulative stress suffered by PV module. A degradation model for the adhesion strength is developed and the activation energy is obtained. Outdoor prediction example is given based on environmental data in Loughborough and Denver.

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## Experiment

Accelerated tests were conducted in environmental chamber at four different damp heat conditions.

| RH / T | 85% | 65% |
|---|---|---|
| 95°C | X | |
| 85°C | X | X |
| 65°C | X | |

**Fig. 1:** Mini PV module after laser cutting. 100mm x 120mm, frameless P-Si

The backsheet of PV module is cut by laser into several strips (See **Fig. 1**). Laser is a quick and precise cutting method with accurate control of cutting depth. Each of the strips is peeled off using a specific peel test machine before and after certain time intervals during ageing (See **Fig. 2**). The peel angle is 90° and the peel speed is 50mm/min. Visual detection is also conducted after removal from chamber each time.

**Fig. 2:** Peel test

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## Degradation Results

Several types of defects are observed after visual inspection. The most severe ones are shown in **Fig. 3**.

**Fig. 3.** Visual detection resutls with bubble near electrode (left), moistrue ingress (middle) and edge/ corner delamination (right)

Adhesion strength results are plotted in **Fig. 4** together with the standard deviation of the results for each sample (**Fig. 5**). The strength can be modelled by following equation:

$$S = S_0\, e^{-\left(\frac{t}{t_{del}}\right)^{\beta}}$$

Where S is adhesion strength at time t, $S_0$ is the strength without degradation, β and $t_{del}$ are assumed to be function of stress levels having an influence on degradation slope which need to be further investigated to understand the degradation behaviour.

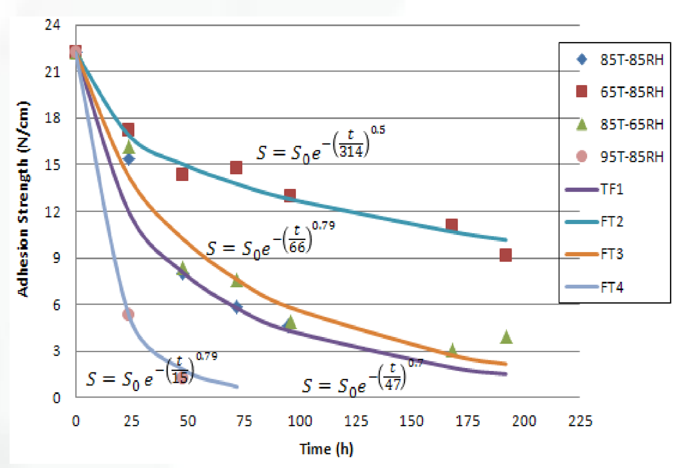

**Fig. 4:** Adhesion strength vs. time at different damp-heat conditions.

Both T and RH are accelerators of the degradation. The rate of T acceleration is faster than that of RH.

Acceleration factors around 3-6 in testing time is achieved for the other three conditions compared with that at 65°C T and 85% RH.

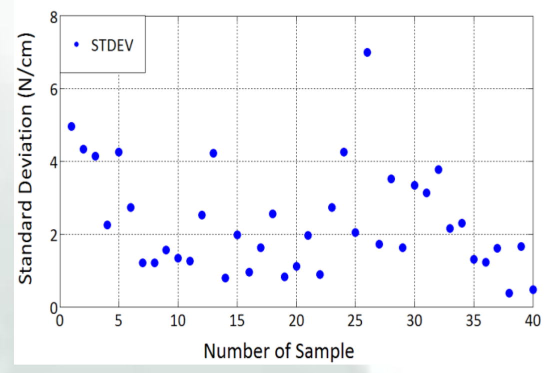

**Fig. 5:** Standard deviation for each module with ten strips

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## Kinetic Stress Model

An empirical kinetic model is developed by assuming that the rate of adhesion degradation is proportional to moisture concentration at the interface of backsheet / encapsulant and the reaction rate constant is Arrhenius dependent. It can be expressed as following:

$$\frac{\Delta S}{\Delta t} = R_D \propto f\,(RH)\, e^{-\frac{E_a}{RT}}$$

Where f (RH) is a function of relative humidity; Ea is activation energy, R is gas constant (8.314J/K·mol) and T is absolute temperature in kelvin.

For the first step, f(RH) is assumed to be proportional to RH in the air:

$$\frac{\Delta S}{\Delta t} = R_D \propto RH \cdot e^{-\frac{E_a}{RT}}$$

A concept of "stress dose" is developed for the quantification of accumulative stresses (**Fig. 6**) which is actually the right part of the above formula.

Ea need to be obtained which determines the acceleration factor.

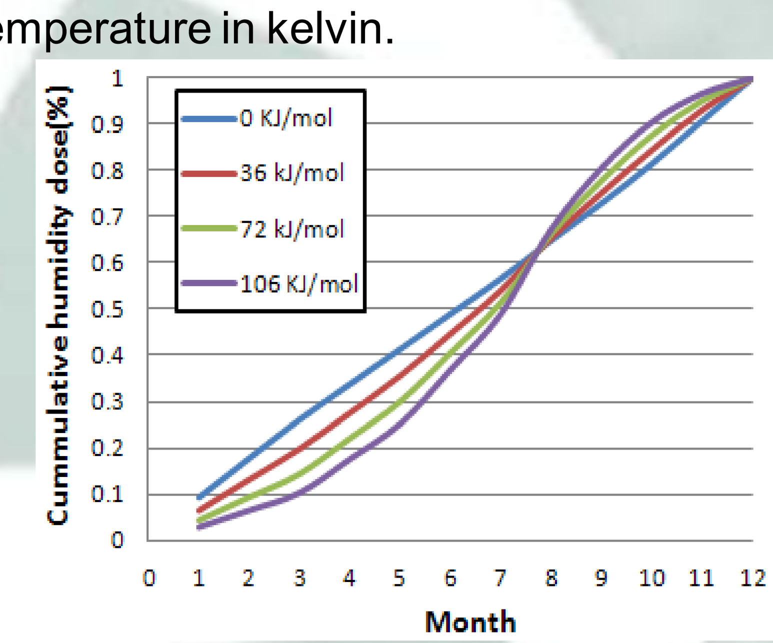


**Fig. 6.** Relative humidity dose in Loughborough with different Ea values

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## Arrhenius behaviour and Ea

A linear relationship can be obtained by taking natural logarithm of $R_D$ and $\frac{1}{T}$.

$$\ln R_D = -\frac{E_a}{R}\frac{1}{T} + \ln(k \cdot RH)$$

Ln $R_D$ vs. $\frac{1}{T}$ plot is shown in **Fig. 7.** at constant RH of 85% but varying T of 95°C, 85°C and 65°C. A linear line is observable, allowing Ea to be calculated:

$$-\frac{E_a}{R} = \text{slop} = -6202.4$$

$$E_a \cong 51\ KJ/mol$$

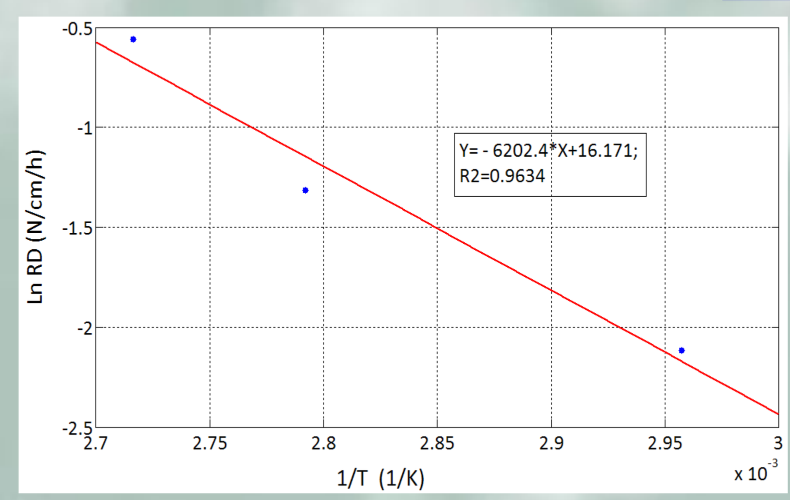


**Fig. 7:** The relationship between Ln $R_D$ and the reverse of temperature

A linear relationship is obtained by plotting the changes of adhesion strength and temperature dose $(e^{-\frac{E_a}{RT}} \cdot \Delta t)$ (**Fig. 8**). This proved the linear proportional dependent of $R_D$ on RH.

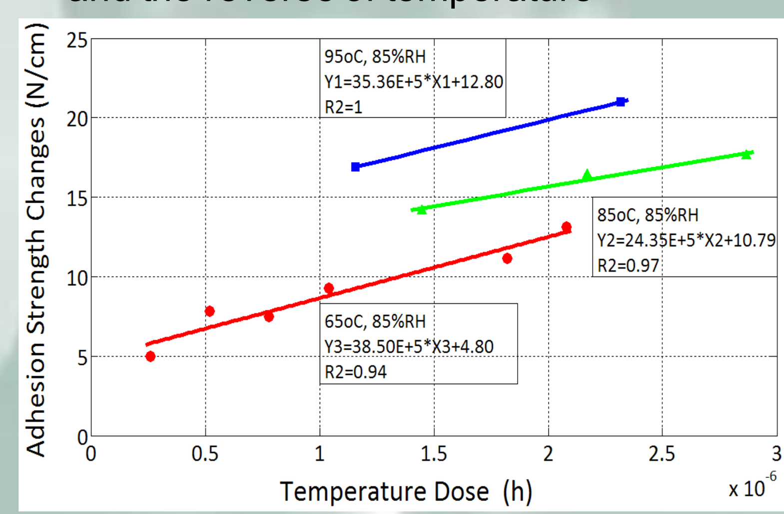


**Fig. 8:** Changes of adhesion strength vs. temperature dose

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## Outdoor & Indoor Prediction

Outdoor exposure time to achieve equivalent indoor degradation can be calculated as following:

$$\Delta t_{out} = \frac{RH_{in}\exp(-\frac{E_a}{RT_{in}})}{RH_{out\_eff}\cdot\exp(-\frac{E_a}{RT_{out\_eff}})}\,\Delta t_{in}$$

Effective T and RH for outdoor is obtained (example in **Fig. 9**):

$$\sum (RH_{out}\, e^{-\frac{E_a}{RT_{out\_eff}}}) = \sum RH_{out} \cdot e^{-\frac{E_a}{RT_{out}}}$$

$$\sum RH_{out\_eff} \cdot e^{-\frac{E_a}{RT_{out}}} = \sum RH_{out} \cdot e^{-\frac{E_a}{RT_{out}}}$$

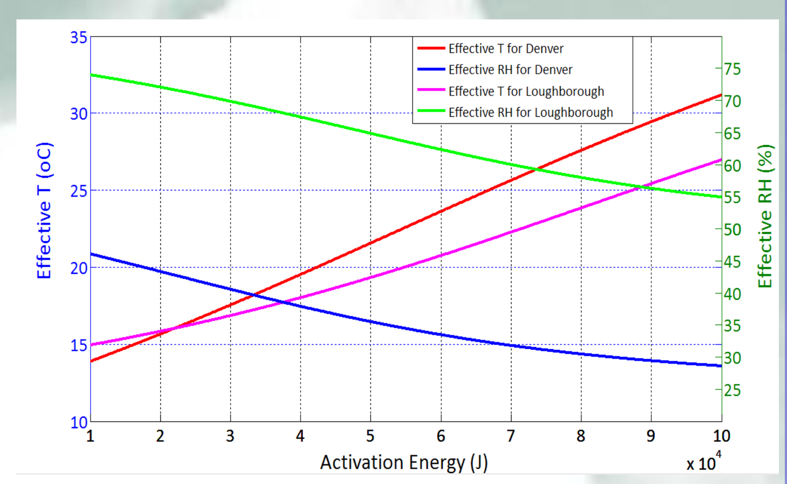

**Fig. 9:** Effective temperature and relative humidity in Denver and Loughborough

The subscript of out and out_eff represent measured and effective value for T & RH.

Module T need to be transformed from ambient temperature Tamb:

$$T_{mod} = T_{amb} + \frac{(NOCT-20)\times G}{800}$$

NOCT is Nominal Operating Cell Temperature. 47° is taken in this study.

Different Ea:
Exponential increase of outdoor time (**Fig. 10**). (no other stresses induced degradation is assumed)

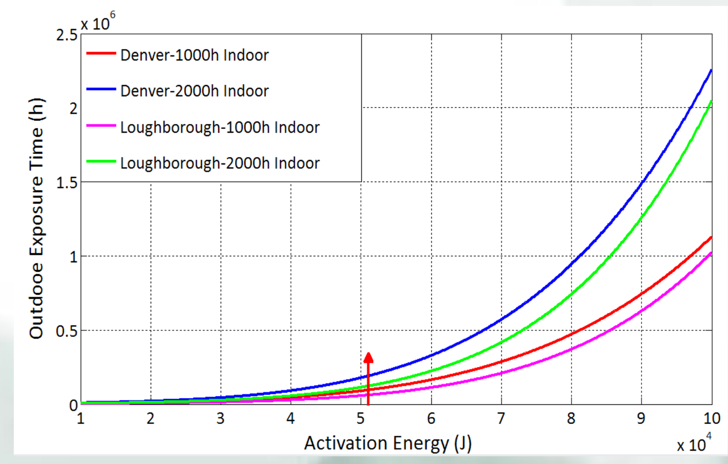


**Fig. 10:** Corresponding outdoor exposure time at Denver and Loughborough for an indoor exposure of 85°C and 85%RH

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## Conclusions and Future Work

Peel test at different stress levels are conducted for commercial mini-modules. An example of the result is shown in **Fig. 11**.

A kinetic model for adhesion strength degradation between backsheet and encapsulant of PV module is established with an Arrhenius temperature acceleration and linear proportion of relative humidity.

Activation energy is obtained for the mini-module enabling outdoor prediction.

Future work will focus on analysing the effects of relative humidity on degradation model and how the moisture degrade the strength. More testing conditions are needed to improve accuracy of the fitting results. Delamination prediction will be conducted with cooperation of the University of Nottingham in UK.

As peel test is influenced by factors like mechanical property of polymer, geometry of strips, peel speed, peel angle etc. The mechanics of peeling are also going to be investigated.

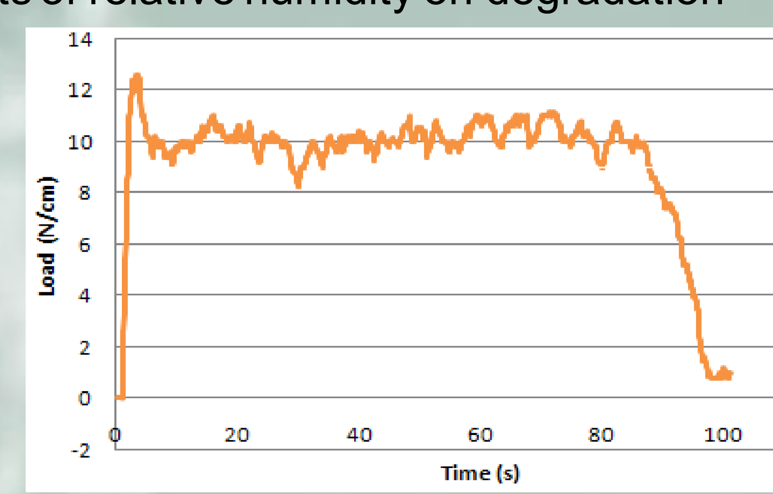


**Fig. 11:** A peel test result

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