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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.

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

<table>
<thead>
<tr>
<th>RH</th>
<th>T</th>
<th>85%</th>
<th>65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>85°C</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80°C</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65°C</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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

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:

\[ S = S_0 e^{-\frac{t}{\tau}} \]

Where \( S \) is adhesion strength at time \( t \), \( S_0 \) is the strength without degradation, \( \beta \) and \( \tau \) 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.

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.

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:

\[ \frac{dS}{dt} = \frac{S_0}{\tau} \exp \left( \frac{-E_a}{RT} \right) e^{-\frac{t}{\tau}} \]

Where \( t \) (RH) is a function of relative humidity. \( E_a \) is activation energy. \( R \) is gas constant (8.314 J/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:

\[ \frac{dS}{dt} = \frac{S_0}{\tau} \exp \left( \frac{-E_a}{RT} \right) e^{-\frac{t}{\tau}} \]

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. \( E_a \) need to be obtained which determines the acceleration factor.

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.