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**Backsheet Degradation under Salt Damp Heat Environments -
Enabling Novel and Innovative Solar Photovoltaic Systems Design
for Tropical Regions and Sea Close Areas**

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Abstract

Photovoltaics technology actually makes the most sense in tropical regions where the sunlight intensity is maximum. Yet traditional PV systems are mostly designed for the northern hemisphere markets, as these are the biggest markets of solar PV systems currently. These PV systems are designed to withstand gusty winds, heavy snows and severe hail impacts. This is thus largely an over design for use in tropical regions. At the same time, this design is also not necessarily the most optimum for tropical regions with many islands, like Indonesia. Exposure to high-angle sunlight onto the PV systems could lead to lower photon capture to the solar cells, while interactions of these traditionally designed PV systems with extreme acid rains and heavy concentration of salt and minerals from seas could lead to premature degradation of the polymer materials inside the PV system. This could in turn instigate corrosion in the metallic interconnects which might then cause electrical shorts and charging/burning and possibly even big fires. Some of our preliminary results on material research that are the pre-requisites of novel and innovative PV system design for these unique regions will be presented.

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1. Introduction

A solar PV module typically is a sandwich of a glass, a front encapsulant layer, a stringed cell assembly, a back encapsulant layer and finally a backsheet. This sandwich is laminated together into one unit and then framed by aluminum frame.

Backsheet as the most outer layer of a module on the back side (ie. on the non-sun facing side) has direct contact to the environment and provides long-term protection to the solar module. The key functions of backsheet are: protecting module from puncture and abrasion, minimizing moisture vapor ingress, and isolating the cells and any electrical connection from the environment. Consequently, backsheet must have excellent weather and mechanical durability. The most common design for backsheet materials would be what is known in the industry as TPE, a sandwich of three kinds of polymers – Tedlar (which is the commercial name of a Poly Vinyl Fluoride), the PET (which is Poly Ethylene Terephthalate) and EVA (which is Ethylene Vinyl Acetate).

There are many evidences of PV module corrosion installed in tropical regions and sea close areas, where the environments are very humid and may contain heavy concentration of salt and mineral [1-6]. High humidity could lead to delamination of module encapsulants whereas high salinity could corrode the metal interconnection within the solar module components leading to potential big fire. All in all, these phenomena can accelerate faster degradation of the solar module within only few years of operations.

Since backsheet is the most outer layer of a module and has very important roles in protecting solar module, the authors would like to investigate the backsheet materials integrity (such as tensile strength) dependency on the combined salinity - humidity parameter. This area of investigation has not been much studied in the literatures while the effect of sole humidity on backsheet integrity has been more widely reported [7-11].

2. Experiment Method

We use two types of commercial backsheets, A and B (for company confidential reasons with our partner who supplied the materials for the present study, we could not specify the actual commercial names of the materials). Backsheet A is a typical/traditional backsheet material, whereas Backsheet B is a relatively new backsheet material.

For tensile strength measurement purpose, these backsheets are cut into small stripes (Figure 1 (a)).

Stripes were exposed to damp heat and salt damp heat chambers at 85° C and 100° C. At the 85° C temperature, samples were also exposed to relative humidity (RH) of 85% and 100% (Figure 1 (b)), while at the 100° C temperature, samples were only exposed to relative humidity (RH) of 100% . Samples of each backsheets (5 stripes each) were removed from the ovens periodically and their tensile strength was measured. Here we take the yield strength/stress point from each of the stress-strain curve to represent tensile strength as the yield stress point can typically be more unambiguously determined compared to the ultimate tensile strength.

Activation energy (The minimum energy which a pair of colliding molecules must possess in order for reaction to take place) between water molecule and polymer chain is taken here as a measure of backsheet material integrity. It is calculated using Eq. [1] as suggested by McMahon *et al.* [12] based on the tensile testing strength measurements of the backsheet specimens as described above. Detail of activation energy (E_a) calculation is described in Sec. 3.4 following Ref. [12].

Much of the experimental work and expertise, we gained through close collaboration with Prof. Arief S. Budiman's lab/group at the Singapore University of Technology and Design (SUTD) especially in the areas of solar PV materials degradation, fracture mechanics and testing. This lab/group has been acknowledged recently and widely accepted as one of the centers for expertise in solar PV materials research especially in the area of silicon PV cell fracture mechanics and advanced silicon-based systems mechanics and reliability [13-20].



Fig. 1. (a) Backsheet stripes; (b) Backsheet stripes in test chamber

3. Results

The results of the tensile strength measurements as a function of time (hours) are presented in Figures 2 through 4. The uncertainty of the failure time measurements is determined to be approximately ± 20 hours. The most important source of this uncertainty is the natural variation within the failure times of each of the 5 stripes to represent each backsheet and condition.

Figures 2 through 4 show an abrupt change at the slope of each curve, which is defined as failure point. At this failure point, sudden embrittlement occurred in the material, where the slope of the degradation changes into something that is more rapid degradation. The higher the temperature and the relative humidity are, the sooner the material failed.

3.1. Experiment condition: 85° C, 85% RH

Table 1. Failure Time

Backsheet Type	Failure Time (hours) (Sudden Embrittlement Occurred)
A (regular damp heat chamber)	2058
B (regular damp heat chamber)	2351
C (Backsheet A in salt damp heat chamber)	2408

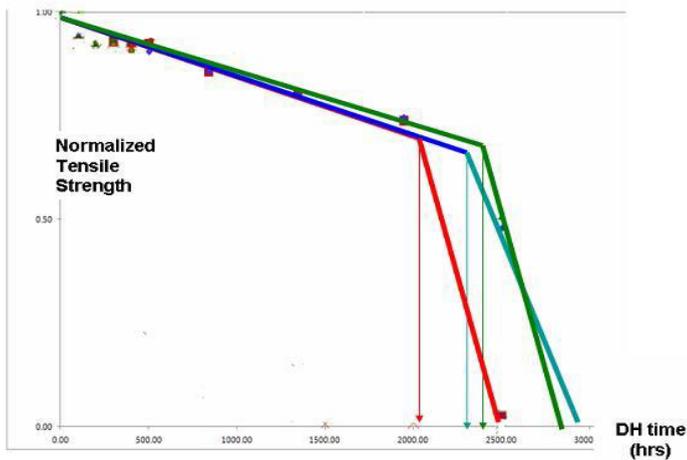


Fig. 2. Tensile strength as a function of time (hours)

The failure time for Backsheet D (which is Backsheet B tested in salt damp heat chamber) is missing here, as well as in the condition 85° C, 100% RH (Section 3.2 below), as at the time of the manuscript submission/reporting, both conditions have not resulted in observable failure points. These conditions are less stringent compared to the third condition, which is 100° C, 100% RH (Section 3.3), which already resulted in an observable failure point for Backsheet D (the yellow curve in Fig. 4). However, since all three conditions (85° C/85% RH, 85° C/100% RH, and 100° C/100% RH) are needed to solve the analytical solution for activation energy E_a in Eq. [1], the E_a for the Backsheet D will not be determined in this present manuscript.

3.2. Experiment condition: 85° C, 100% RH

Table 2. Failure Time

Backsheet Type	Failure Time (hours) (Sudden Embrittlement Occurred)
A (regular damp heat chamber)	1684
B (regular damp heat chamber)	2175
C (Backsheet A in salt damp heat chamber)	2168

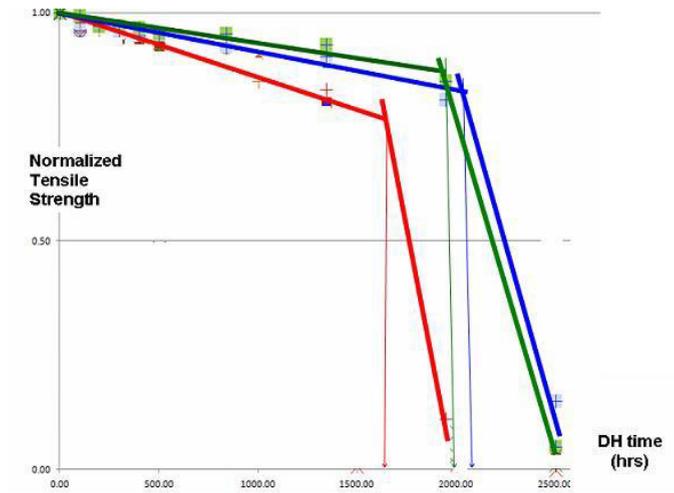


Fig. 3. Tensile strength as a function of time (hours)

3.3. Experiment condition: 100° C, 100% RH

Table 3. Failure Time

Backsheet Type	Failure Time (hours) (Sudden Embrittlement Occurred)
A (regular damp heat chamber)	357
B (regular damp heat chamber)	446
C (Backsheet A in salt damp heat chamber)	418
D (Backsheet B in salt damp heat chamber)	564

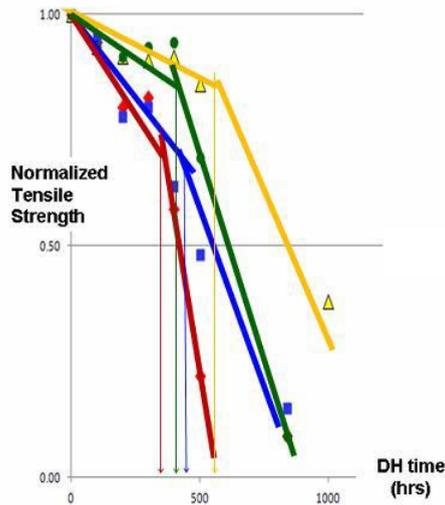


Fig. 4. Tensile strength as a function of time (hours)

At 100° C and 100% RH, the failure time between backsheets A and B, which were tested in damp heat chamber and backsheets C (A) and D (B), which were tested in salt damp heat chamber, are almost the same within the experimental error.

3.4. Activation Energy

The activation energy, which is the minimum energy required by water molecule and polymer chain reaction to take place, was calculated from the experimental data following equation [1] from Ref. [12]:

$$k_1 = C(H)^n \exp\left(\frac{-E_a}{RT}\right) \quad (1),$$

where k_1 is the hydrolysis rate (day), C is a constant (empirically determined), H is the relative humidity (100% RH = 1), n is a relative humidity exponent (empirically determined), E_a is the activation energy (kcal/mole), T is the absolute temperature (° C), and R is the gas constant (Its value is nearly 2.0 calories per ° C, per mole).

The hydrolysis rate, k_1 , was obtained from the failure time (see Table 1-3) multiplied by a constant (0.0031). The detail of k_1 and E_a calculations can be found in Ref. [12].

Given four variables for each experiment condition (k_1 , H , R , T), we can determine E_a , n and C for each experiment condition.

Table 1 shows the calculated E_a here for each backsheet. The activation energy is nearly the same for all backsheet within the experimental error. This means that the amount of energy required by salt water molecules to react with polymer chain is similar to that of water molecule and polymer chain reaction.

Table 4. Calculated activation energy

Backsheet Type	E_a (kcal/mole)
A (regular damp heat chamber)	28.67
B (regular damp heat chamber)	28.53
C (Backsheet A in salt damp heat chamber)	28.79

The dependence on humidity (the exponent n), which represents how sensitive the materials properties would change with respect to a change in humidity, is a subject of our ongoing investigation. This topic is a much more involved and complicated, and thus requires more in-depth data analysis. This will be reported in our next report.

4. Conclusion

From our experiment, we conclude that either water vapor or salt mist causes embrittlement of the backsheets. Backsheets C and D which were tested in salt damp heat chamber perform about the same as backsheet A and B which were tested in regular damp heat chamber, as shown from both the E_a measurements as well as the failure point data.

Yet, we see widespread evidences of salt/water ingress, for instance in the form of connector corrosions which were found from installed traditional PV modules in tropical/sea close regions. Given the experimental results of the present study, where it suggests that the integrities of the backsheets and how they degrade with water vapor and salt mist are not very significantly different, this could thus indicate that the corrosions could instead result from water vapor/salt ingress through the edges of module frames or through delaminated/cracked backsheets. This possibility is the subject of our ongoing investigations.

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