

# IMPACT OF THE EVA YELLOWING OF 20 COMMERCIAL MODULES ON PERFORMANCE AND DURABILITY

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**ABSTRACT:** This paper aims to analyze 20 photovoltaic modules randomly selected from 2 PV power plants where high percentage of their modules presents “yellow” appearance. Modules were manufactured in two different factories and all of them were subjected to five tests: visual inspection, insulation test, maximum power measurement, cure degree of EVA (gel content) and adhesion strength test between EVA-glass and EVA-back-sheet interfaces, respectively. During test, it was found out that visual discoloration was caused by EVA photodegradation in some modules and by back-sheet photodegradation in others. Main conclusion observed from results is that discoloration does not affect to electrical performance after one operation year. Also, results show that yellowing phenomenon has not decreased adhesion properties in module components under commercial values. Moreover, direct relation between discoloration and cure degree of EVA was not found.

**Keywords:** PV module, Quality Control, Testing and Characterisation

## 1 INTRODUCTION

Ethylene vinyl acetate (EVA) is the polymeric pottant widely used in the encapsulation of crystalline silicon photovoltaic modules. The pottant protect the delicate silicon solar cells in the module. Apart from structural support, EVA provides electric and physical isolation with good thermal conduction of active parts. Other of its functions is the optical coupling between the solar cells and frontal glass of the module.

EVA has been in commercial use since 1981[1] and several research groups have reported discoloration, from yellow to brown, in field-aged modules since the 1990s [2][3]. NREL studied extensively degradation and discoloration mechanism for laminated and cured commercial EVA films and the effect of EVA discoloration on silicon cell efficiency [4]. In addition, new formulations of EVA were developed to improve photostability with selected stabilizers, antioxidants and curing agents [5].

TPT and TPE are the back-sheet widely used in PV modules manufacturing. TPT is a three-layer laminate: Tedlar™-Polyester-Tedlar™, and TPE is a Tedlar™-Polyester-EVA laminate. The polyester is a barrier layer and provides of electrical isolation, and Tedlar™ is also a barrier layer very weatherable and temperature resistant. PV module components providers have informed to us that there are in the market other types of back-sheet, PPE, PEN-based, etc, which theoretically have same properties than TPT and TPE. Failures in permeability have been detected in Tedlar™ after long number of humidity-freeze cycles, which cause oxygen and water vapour permeate through the back-sheet to produce yellowing due to oxidation processes [6].

Nowadays, one decade later than studies above mentioned, Spanish end-user of photovoltaic PV modules have reported numerous instances of yellow discoloration to ENERTIS SOLAR. ENERTIS SOLAR is a private Spanish IEC 17025 accredited laboratory for PV modules characterization focused in quality control of PV facilities.

This work aims to show the results of partial characterization of 20 commercial PV modules with “yellow” visual appearance focused on impact on maximum power and properties affecting to durability as

adhesion strength and cure degree of EVA. These modules have been operating during approximately one year just before characterization.

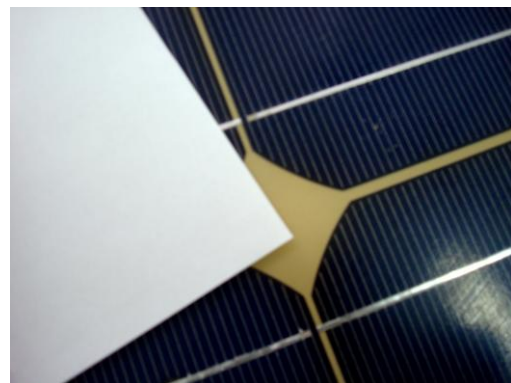
## 2 EXPERIMENTAL PROCEDURE

20 PV modules from 2 different manufacturers were analyzed. Table I shows number of samples of each manufacturer and the visual appearance of laminate. These modules were randomly selected from 2 PV power plants which present high percentage of discoloured modules. Modules with normal appearance and with discoloration were analyzed to compare results.

**Table I:** Summary of samples

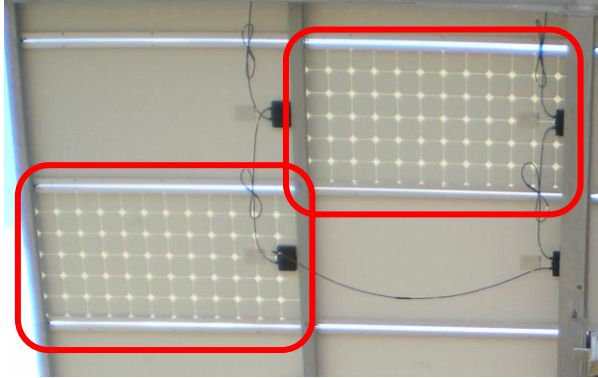
Manufacturer	Number of samples	Visual appearance
A	5	Discoloration
	5	Normal
B	3	Discoloration
	7	Normal

Fig.1 shows and example of discoloured module. White paper was included to make comparison of colour easier.



**Figure 1:** Module from Manufacturer A with discoloration.

An important detail is that modules from manufacturer A were constructed with different back-sheet as Fig. 2 shows. Back-sheet of discoloured modules is brighter and more translucent than typical TPT foil.



**Figure 2:** Back-sheet of modules from Manufacturer A. Marked modules presented discoloration in laminate.

Samples were characterized with a 5- test sequence as follows:

- a. Visual inspection.
- b. Peak power measurement.
- c. Electrical isolation.
- d. Gel content determination of EVA by extracting with toluene.
- e. Adhesion strength 90° measurement between EVA-glass and EVA-back-sheet, respectively.

Tests a, b and c were carried out according to IEC 61215.

### 3 RESULTS

#### 3.1 Visual inspection

Serious defects specified in section 7 of IEC 61215 have not been detected during the visual inspection, so all modules have satisfactorily passed test. Also, visual inspection was focused in detection of any possible discoloration. Detected modules with discoloration present yellow appearance. Table II shows results.

#### 3.2 Peak Power measurement

I-V curves of modules have been obtained with a Class AAA solar simulator according to IEC 60904-9. Temperature and irradiance corrections have been executed according to IEC 60891. Table II shows peak power measurements in STC and its difference with nominal power. Also, difference between measured values and nominal power is exposed.

Comparison between initial maximum power in fabric and measured value in this test is not possible because flash list have not been provided. Estimated uncertainty of peak power measurement is  $\pm 1.6\%$ .

Results show that maximum power of modules from Manufacturer A is mostly close to nominal power. Comparison between peak power of discoloured and normal modules shows that peak power of modules from Manufacturer A is not affected by discoloration.

**Table II:** Results of visual inspection and maximum power measurement at STC.

Manufacturer – Module	Visual appearance	$P_{mpp}$ (W)	$P_{nom}$ (W)	$\Delta P$ (%)
A-1	Discoloration	222.64	220	+1.20
A-2	Discoloration	222.07	220	+0.94
A-3	Discoloration	221.16	220	+0.53
A-4	Discoloration	214.32	210	+2.06
A-5	Discoloration	171.02	175	-2.27
Average				<b>+0.49</b>
A-6	Normal	221.26	220	+0.57
A-7	Normal	224.24	220	+1.93
A-8	Normal	222.83	220	+1.29
A-9	Normal	209.49	210	-0.25
A-10	Normal	175.27	175	+0.15
Average				<b>+0.74</b>
B-1	Discoloration	161.73	180	-10.15
B-2	Discoloration	168.48	180	-6.40
B-3	Discoloration	174.30	180	-3.17
Average				<b>-6.57</b>
B-4	Normal	163.93	180	-8.93
B-5	Normal	165.41	180	-8.10
B-6	Normal	169.44	180	-5.87
B-7	Normal	167.00	180	-7.22
B-8	Normal	160.25	180	-10.97
B-9	Normal	159.17	180	-11.57
B-10	Normal	163.61	180	-9.11
Average				<b>-8.82</b>

In case of Manufacturer B, maximum power values are very far from nominal power. This tendency is even worst in normal modules than discoloured ones. With these result we can conclude that low maximum power is not caused by discoloration in modules from Manufacturer B.

#### 3.3 Electrical isolation

The aim of this test is to analyze if the PV module is correctly electrical isolated between its current conductor parts and the frame.

All modules have satisfactorily passed test with any isolation failure due indirectly to discoloration.

#### 3.4 Gel content determination

The purpose of this test is evaluating the gel content of the cross-linked ethylene vinyl acetate by extracting with toluene. There is not a standard where minimum gel content was established. Desired values between 80-90% are mentioned in studies about EVA encapsulant [7][8][9]. However, minimum acceptable value of 65% has been reported by Jet Propulsion Laboratory (JPL), which specifies that EVA with gel content over 65% may be regarded as acceptably cured [10].

Results are exposed in Table III. According to criterion above mentioned we can see that cure degree of EVA in all modules has been satisfactory. Also, comparing values between discoloured and normal modules we conclude that discoloration is not produced by incorrect cure processing.

#### 3.5 Adhesion strength 90°

This test gives information about how strong is the adhesion between different layers in the laminate. Low adhesion could cause future delaminations.

Strips of 1 cm width were cut at back using a utility knife, being sure to cut strips attached to the glass too in the adhesion strength measurement of EVA/glass interface.

Each module was tested in 3 different positions: 1 test in 2 opposite corners and the other one in the centre of the module, forming a diagonal. Values are shown in Table III. These values were obtained as the average between three positions.

**Table III:** Results of gel content and adhesive strength tests.

Manufacturer – Module	Visual appearance	Gel content (%)	Adhesive Strength EVA (N/cm)	
			Glass	Back-sheet
A-1	Discoloration	65	50	10
A-2	Discoloration	75	45	12
A-3	Discoloration	75	44	14
A-4	Discoloration	75	50	11
A-5	Discoloration	65	44	14
A-6	Normal	75	48	19
A-7	Normal	75	45	14
A-8	Normal	75	50	11
A-9	Normal	65	43	13
A-10	Normal	75	42	12
B-1	Discoloration	75	49	24
B-2	Discoloration	75	50	20
B-3	Discoloration	75	43	19
B-4	Normal	75	43	7
B-5	Normal	75	49	17
B-6	Normal	75	49	18
B-7	Normal	75	50	22
B-8	Normal	75	50	20
B-9	Normal	75	44	16
B-10	Normal	75	44	28

There is not a standard where minimum adhesion strength was established. However, there are works about adhesion strength in literature studying factors affecting to adhesion as [11], but they do not specify minimum acceptable values. The only information about this was obtained contacting directly with manufacturers. Some of them specified that, in their internal quality control criteria, minimum acceptable adhesion strengths in EVA-glass and EVA-back-sheet interfaces are 30 N/cm and 10 N/cm, respectively.

According to this criterion, we can see that adhesion strength values shown in Table III are satisfactory for all modules. Comparing values between discoloured and normal modules, it is obvious that adhesion strength is not reduced by discoloration.

#### 4 BACK-SHEET PHOTODEGRADATION

During adhesion strength test on modules from Manufacturer A, we found out that cause of discoloration is not EVA photodegradation but back-sheet photodegradation.

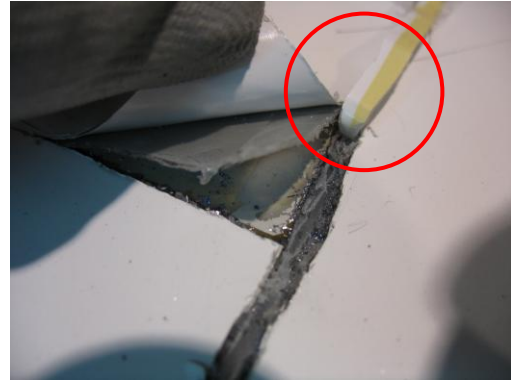
This situation is show in Fig. 3 where strips peeled is not discoloured where was covered by solar cell. It can be seen in Fig. 2 that these discolored modules was assembled with a different back-sheet film, probably of less quality.

However, discoloration of modules from Manufacturer B was caused by EVA photodegradation.

#### 5 CONCLUSIONS

20 photovoltaic modules have been randomly extracted from 2 PV plant which present high percentage of modules with discoloration in laminate after one operation year. These modules have been characterized to

investigate, on the one hand, if discoloration is affecting to their electrical performance with peak power measurement, and on the other hand, if this effect damages durability of laminate. In addition, investigation about gel content of the cross-linked EVA has been carried out to find out possible relation between yellowing effect and cure degree.



**Figure 3:** Detail of back-sheet photodegradation. Strip present discoloration where was not covered by cells.

Comparing results of maximum power measurement at STC of discoloured and normal modules, we can conclude that yellowing after one operation year is not affecting to electrical performance in the analyzed modules. Note that “yellowing” can be considered as the initial manifestation of the “browning” phenomenon. Studies of F.J. Pern et al. reported that the application of a pale yellow filter has little effect on the output current of PV cells because cells have relative low sensitivity to short wavelength light [11]. This implicates that is necessary to tailor discolouring phenomenon and its effect on electrical performance during module lifetime. Thus, end-user of PV plant can control that their PV modules satisfy performance warranty conditions.

Gel content has been measured by extracting with toluene in three samples per each module. Results show that normal and discoloured modules present acceptable cure degree and no relation between discoloration and cure has been found out.

Also, adhesion strength has been measured by peeling strips in three samples of each module. Satisfactory adhesion strength values have been obtained in all modules, not observing decreasing of adhesion due to yellowing phenomenon.

During peeling we have found out that discoloured modules from Manufacturer A, which were constructed with different back-sheet than the rest of modules, present discoloration caused by back-sheet photodegradation instead of EVA photodegradation. This discoloration is not affecting to adhesion in EVA-glass interface after one operation year. These modules should be control paying attention in any evidence of delamination.

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