The Effect of Degree of Gel Content of EVA Encapsulant on the Properties of Encapsulant Itself and Finally on the Reliability of the Solar Module in the Field

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Abstract: The present study involve the effect of the gel content of the EVA on its performance parameters like Tensile Strength, Elongation, Transparency, Yellowness Index, Volume Resistivity, Adhesion strength, Environmental stability & UV stability; and finally; the net impact of these properties on the performance and durability aspects of PV modules.

A Cross-linked EVA Encapsulant with varying degree of gel content was used to conduct this study. Tensile Strength, Elongation, Transparency, Yellowness Index, Volume resistivity and Adhesion strength were measured on EVA sheet having different gel contents.

The Environmental stability evaluation of EVA sheet was done by doing damp heat test on the EVA sheets having different gel content. The performance parameters were measured post damp heat 500, 1000, 1500, &2000 hrs

It was found that there was a critical range of gel values needed in the EVA sheet to exhibit an acceptable performance by the Encapsulant in a PV Module. There was a significant change in performance parameters of EVA sheet, above and below the critical gel content range.

Keywords: EVA crosslinking rate, Module reliability.

1 Introduction:

An encapsulant in a Photovoltaic (PV) module is a polymer used for binding all the components together. It provides protection to the cells from moisture, foreign impurities and mechanical damages. An ideal Encapsulant possess optimal Tensile Strength, Elongation, High Transmittance of light, lower Yellowness Index, higher Environmental and UV stability, high volume resistivity and adhesion strength. The need of such important properties makes Encapsulant a vital component for the performance of a PV module.

Ethylene-Vinyl Acetate Copolymer (EVA) is one of the widely used encapsulation material in Photovoltaic (PV) modules [1]. The EVA encapsulant used for PV modules is a cross-linkable polymer and its degree of crosslinking is defined by “gel content”. The most of the important characteristics of the EVA Encapsulant material is dependent on its gel content.

As the industry is growing very fast, there is shortage of skilled manpower to produce quality product. The above study shall provide a reckoner to the professionals / engineers in the component and module manufacturing industry for making correct decisions. The objective of the study is to share one of the critical parameters of Solar PV module manufacturing which ensures the reliability of the solar PV modules.

Solar panels are expected to have a guaranteed service time of 20 to 30 years with typical degradation rates of 0.3– 0.5%/a of STC power output for crystalline modules [2]. The quality & reliability of the manufactured Solar PV module depends on the lamination quality of module. Lamination is the first and most important process which needs utmost care during the module making process. The lamination process involves the encapsulation of Solar PV cell string between glass & backsheet with help of EVA encapsulant.

The most commonly used EVA encapsulants are cross linkable type which cross-linked during lamination process. For a given Encapsulant, the degree of crosslinking depends on the lamination temperature and the lamination time. The major parameters of EVA which drive the Solar PV module reliability are transparency, tensile strength, Elongation, refractive index, volume resistivity and dielectric strength.

The commercial available EVA foils are in the form of sheet having all required additive mixed. The crosslinking happens during the lamination process and the chains of EVA will get rearranged during the process.

It is very important to understand the effect of the crosslinking degree (Gel content) on the performance parameters of EVA which drives the module Reliability. The present work will give awareness to the industry on how the gel content is related to module lamination and finally on the performance of the Modules.

There were several works already done on the subject but this work is containing the concept of how a module manufacturer can choose a right EVA Encapsulant assure the quality of module which they are selling.

2 Experimental Procedures

2.1 Sample Preparation

A fast cure EVA Encapsulant with 28% VA content was taken for this study. The cured EVA sheet were prepared by keeping one layers of EVA between Teflon sheet on the glass inside the laminator at variable temperature to get variable gel content as shown in fig (1) and Table (1). The cured EVA sheets were prepared to perform UV exposer test, Optical, electrical & mechanical properties testing.

Fig (1): Laminate structure for Cured EVA sheet sample preparation

Samples for adhesion strength test were made as per laminate structure shown in figure (2). The laminates were laminated in vacuum laminator at variable temperature as shown in table (1).

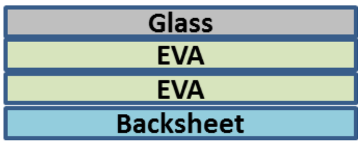

Fig (2): Laminate structure for Adhesion strength sample preparation

Lamination Temperature (°C)	Vacuum Time (minute)	Pressing time (minute)
135	6	8
138	6	8
140	6	8
146	6	8
148	6	8
150	6	8
152	6	8
160	6	8

Table (1): Laminate parameters to get variable gel content for study

2.2 Testing Procedure

2.1.1 Gel content

Gel content test was done by curing two layers of EVA sheet on glass to simulate actual module manufacturing case. Curing was done at lamination parameters shown in table (1). The cured sample was extracted for 20 hrs by Soxhlet process and posts 20 hrs, it was dried for 4 hrs in hot air oven at 105 deg C.

Post drying in hot air oven sample, was kept in desiccator for 1.5 hrs to remove moisture completely. The weighing of sample was done post drying in desiccator. The gel content (%) was calculated by below formula,

Gel content= (Weight of cured EVA before test- Weight of EVA after drying) ×100/ Weight of cured EVA before test

2.1.2 Optical testing

Optical properties like transparency, UV cut off wavelength & yellowness Index of the EVA were measured in UV-VIS spectrophotometer (Shimadzu: UV 2600). The cured samples were prepared as shown in figure (1) at parameters shown in table (1). EVA cured sheets before and after UV exposer were undergone optical testing.

2.1.3 Mechanical testing

The mechanical properties like Tensile Strength & elongation at break of cured film were measured before and after UV exposer as per ASTM D 882 by universal testing machine (Instron).Samples were prepared as shown in fig (1) and curing was done at parameters shown in table (1).

The Adhesion strength of EVA with glass was measured before and after Damp heat test. Samples were prepared as shown in figure (2) at parameters shown in table (1). The adhesion strength test was performed as per ASTM D 903.

2.1.4 Electrical testing

Electrical properties like Volume resistivity of the cured EVA sheet was measured by volume resistivity meter (Keithly) as per ASTM D 257. Samples were prepared as shown in fig (1) and cured at parameters shown in table (1).

2.1.5 Damp heat test

Damp heat (As per IEC-61215) test was performed on laminated samples (fig2) for 500, 1000, 1500, 2000 hrs. The adhesion strength of samples was measured pre & post Damp heat test.

3 Results & Discussions

3.1 Gel content

The gel content or crosslinking degree of EVA encapsulant was mesured on cured samples of EVA . The curing parameters of the sample were as per table (1). The plot between EVA gel content and temprature at constact time is shown in fig (3).

It seems that the rate of crosslinking increased abrouptly from 35 % to 71% as temprature incrased just from 138°C to 140°C. It indicates that temprature plays a very important role for gel content, and at a crtical level, a varation of 2 degC of lamination temprature can increase or reduce the gel content drastically. If we look at gel content at 146 deg C., which is 76% and gel content at 150 deg C which is 85%, there is 9% incrase in gel content while temprature is increased only by 4 deg C. It is clear that the effect of temprature varation on gel content is huge at neighbhorhood of 140 degC rather than neighbourhood of 148 degC.If module manufactures work at 148 degC by considering ± 2 deg C tolerance, then the gel content will always be within 75% and 90%, which is the globaly accepetd range of gel cotent.

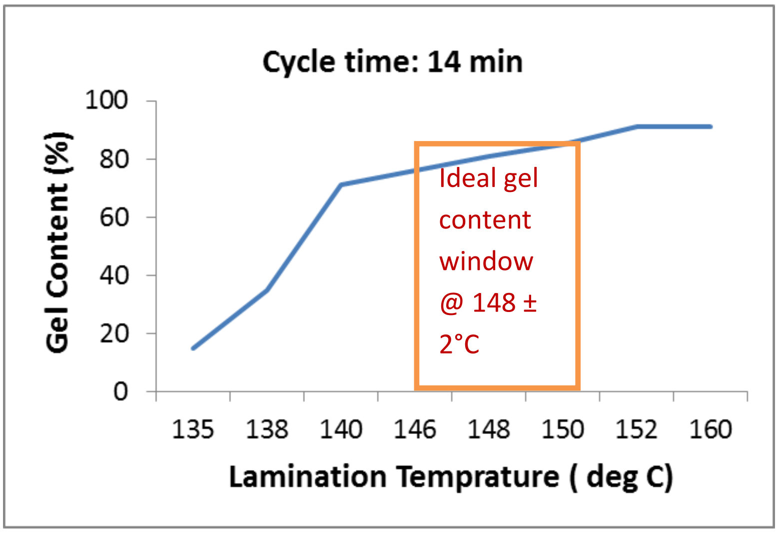

Figure (3): Gel content of EVA with respect to temperature

3.2 Effect of gel content on EVA parameters

3.2.1 Mechanical properteis

The Tensile strength & elongation are the two major mechanical properties of EVA which indicates the performance EVA during aging. Both these properties generally decrease after degradation of EVA. These degradations of the properties affect the module peformance by formation of cracking in cell caused by temprature cycling, by mechanical loading of wind, sand & air strom. It is important to have an optimal tensile strength & elongation in EVA so that post aging, it still retains a minimum value of the machinical properties (≥ 10 MPa, Specification derived from analysis of several TDS of EVA manufacturers).

We can see the effect of gel content on tensile strength of EVA in plot as shwon in figure (4). The EVA tesnsile strength is reaching to a lower limit of 10 MPa after attaining a gel content of 71% and it reached to its maximum value of 17 MPa and remains consistent there-after from 81gel -91% Gel.

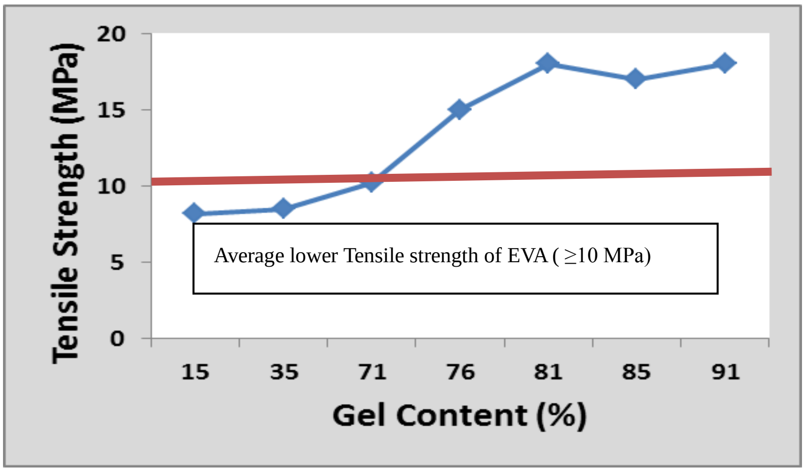

Figure (4): Tensile Strength of EVA with respect to gel content

The uncured EVA has polymer chains which are not cross-linked and having very low tensile strength (3 MPa to 7 MPa). But after crosslinking, the chains are get cross-linked and make a strong network of interlinked chains as shown in figure(5).The crosslinking process is responsible for increased tensile strength & elongation.

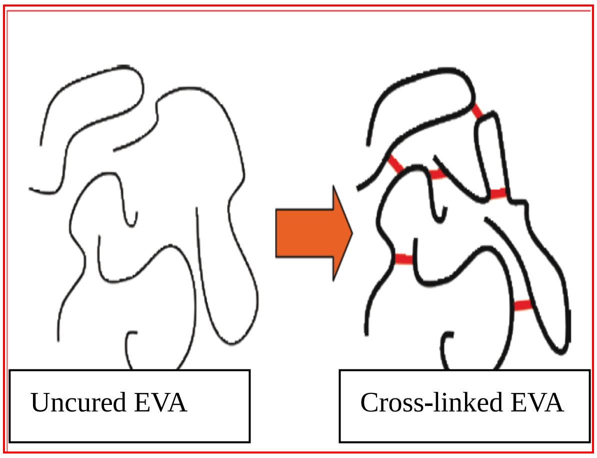

Figure (5): Schematic of EVA crosslinking [2]

The effect of gel content on elongation indicates that there is reduction in elongation with increase in gel content and it was found consistent after crossing a gel content of 71% as shown in fig (6).

The reduction in elongation is because of crosslinking the EVA film. The cross-linking stops internal slippage of modular chains when stress is applied; they rather break and give lower value of ultimate elongation. An optimum get values (degree of cross-linking) maintains a balance between the flexibility and rigidity of the cured material. A too soft encapsulation material (low gel) leads to delamination/bubbles etc as discussed above whereas; a too rigid encapsulation (high gel) causes cell cracks etc, under mechanical abuses.

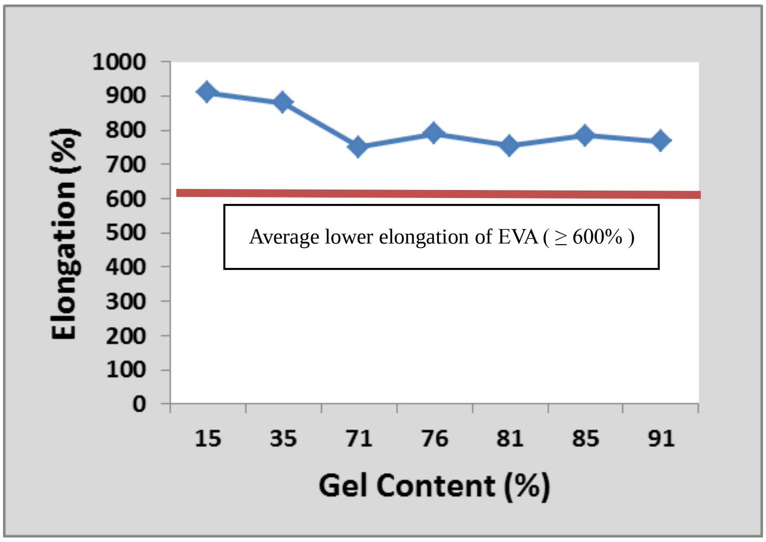

Figure (6): Elongation of EVA with respect to gel content

The tensile strength & elongation are characterized, firstly by, the type of EVA material with respect to its VA content and, secondly, by the value of its gel content. It was found that both the parameters have an acceptable value from 71% to 91% of gel content.

It was found that the average gel content of 85% is the center point. As per point 3.1 it is also clear that there is no significant change in gel content above 85% as a function of temperature.

3.2.2 Optical properteis

The Optical properties of EVA sheet include Optical transmittance, Refractive index, UV cut off wavelength & Yellowness Index. In the study is has been found that there is significant change in refractive index of EVA with respect to gel content [3] and it increases linearly with the increase of gel content. It increases with gel content.

UV cut off wavelength is characteristic of UV absorber added in EVA to block UV irradiation going to the cells. The effect of gel content on optical transmittance & yellowness index was analyzed and shown in figure (7).

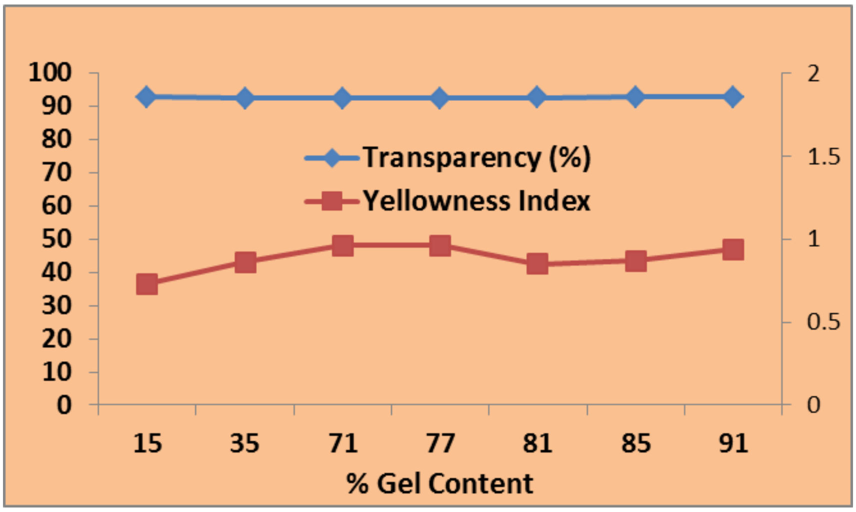

Figure (7): Optical properties of EVA with respect to gel content

As we can see that there is no significant changes in transparency and yellowness index of EVA with respect to its gel content, indicating that even if a module has low gel content also, no immediate effect on the power lose is experienced. This makes job of the module manufacturers difficult in identifying the modules having low gel content, as these modules behave same as a normal module in power measurement. In addition, the un-reacted Peroxide present in the EVA sheet due to low gelling, reacts with other materials like cells, ribbons and bus bars etc. and causes discoloration/de-laminations in the field.

3.2.3 Electrical properteis

The major electrical properties which considered in PV EVA sheets are Volume resistivity & dielectric strength. The effect of gel content on volume resistivity is shown in figure (8). The volume resistivity of EVA increases exponentially with increase in the gel content.

The volume resistivity of EVA in Ohm.cm is defined as the electrical resistance through one centimeter cube of EVA material. The higher gel content leads to less un-used peroxide in the EVA sheet. Peroxide being highly polar, makes the media conductive where ever it is present. Such un-reacted peroxide in the EVA sheet reduces its volume resistivity and hence increases the PID effect. For a higher value of volume resistivity (Low PID), one should ensure a higher value of the gel content and more importantly, least possible un-reacted peroxide presence in the Encapsulant sheet.

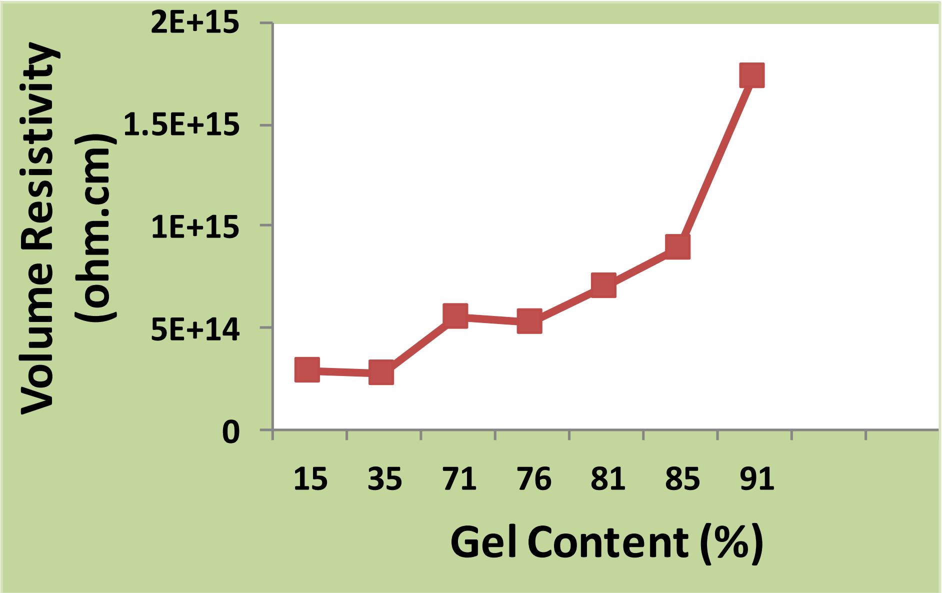

Fig (8): Effect of gel content on volume resistivity

3.2.4 Adhesion strength

The adhesion strength of EVA with glass was measured on samples having diffrent gel contents starting from 15% gel to 91%. In all the cases, the adhesion strength was found to be more than 120 N/cm which is higher than prevailing industry std of >70N/cm.

All samples were exposed to damp heat test for 2000 hrs. The adhesion strength was measured and ploted in figure (9). There is no significant diffrence observed in adhesion sterngth of EVA having gel content from a lowet to highet value.

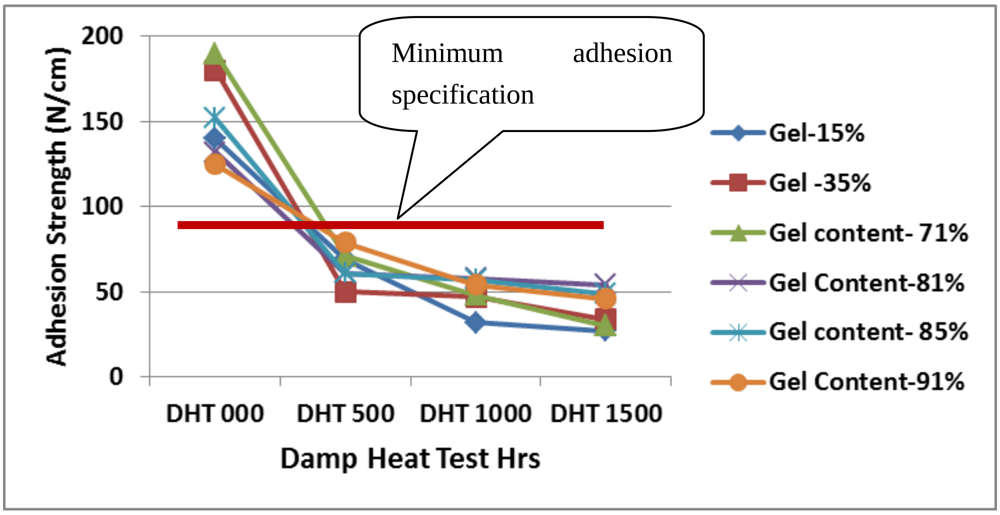

Fig (9): Effect of gel content on Adhesion strength

It was also found that the EVA peel with glass was not smooth in case of gel content 15%. This indicates that the tensile strength of EVA is lower due to less gel content. There was no bubble or delamination found in all samples exposed to damp heat as shown in figure (10).

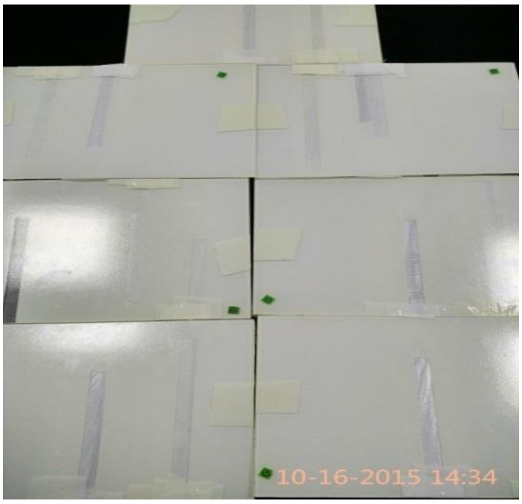

Fig (10): A4 laminates samples for Adhesion strength test

There is no clear relation in gel content and adhesion strength found and both are independent to each other.

3 Conclusions

The Gel content (Degree of crosslinking) of EVA is a critical parameter which is affected strongly by lamination parameters like temperature, time, temperature and pressure uniformity with in the lamination chamber whilst module making process. The mechanical & electrical properties of EVA have strong dependency on gel content while adhesion strength of EVA has no significant dependency on gel content.

To ensure the module reliability in field, the mechanical and electrical parameters of EVA are of prime considerations. The Gel content range of 75%-90% was found optimum between which the EVA properties ensure the desired performance and durability of the PV modules in the field.

4 Refrences

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