

Structure and basic properties of photovoltaic module backsheet films



Klaus J. Geretschläger*, Gernot M. Wallner, Jörg Fischer

Johannes Kepler University Linz, Institute of Polymeric Materials and Testing, Altenberger Straße 69, 4040 Linz, Austria

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ABSTRACT

In this paper commercially relevant backsheets are characterized as to their material and laminate structure and basic optical and mechanical properties. Various multilayer backsheet materials were selected and analysed by optical microscopy, Raman spectroscopy, infrared spectroscopy (FTIR-ATR), thermal gravimetric analysis (TGA), differential scanning calorimetry (DSC), ultra violet visible near infrared spectroscopy (UV/VIS/NIR) and monotonic tensile testing. By Raman and infrared spectroscopy and DSC the polymeric materials of the various layers were identified. Furthermore it was shown for the thermoplastic ethylene vinylacetate copolymer (EVA) layers that three different vinylacetate (VA) contents were used. By TGA a content of inorganic fillers and pigments from about 6%_m to approximately 20%_m was detected. The hemispherical solar reflectance of the white pigmented backsheets was ranging from 0.695 to 0.838. The highest Young's modulus was found in polyvinylfluoride based multilayers while the lowest values were detected for polyamide based structures.

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1. Introduction

To take advantage of renewable photovoltaic energy it is essential to have capable photo electronics properly protected against environmental factors like climate or external mechanical loads. In addition to excellent long term performance encapsulation materials for photovoltaic (PV) modules should be cost efficient and easy to process. Modern PV modules as shown in Fig. 1 are sandwich type structures. The PV cell is often embedded in chemically crosslinked ethylene vinylacetate copolymer (EVA) [1]. The side facing the sun is usually covered by a glass pane. In flexible PV modules polymer based frontsheets are of high relevance. On the back side of a PV module backsheets are used. Backsheets are multilayer laminates made from various polymeric materials and inorganic modifiers. The multilayer structure allows tailoring the optical, thermo mechanical, electrical and barrier properties of backsheets according to specific requirements for PV modules. While for example fluoropolymers like polyvinyl fluoride (PVF, DuPont trade name "Tedlar") provide excellent weatherability, engineering thermoplastics like polyesters (PET) or polyamides (PA) exhibit good mechanical stability and support [2,3]. Regarding fluoropolymers a trend to novel materials is recognizable. As inner layer PVF is partly substituted by less costly EVA. For outer layers polyvinylidene fluoride (PVDF), ethylene

chlorotrifluoroethylene (ECTFE) and tetrafluoroethylene hexafluoropropylene vinylidene fluoride (THV) have been established. Modern fluoropolymer-free constructions become more and more capable [4]. Surprisingly up to now there is no contiguous dataset on backsheet materials available that touches more than a coarse description of the contents involved. Also well-defined minimum requirement for backsheet materials other than a solar reflectance of more than 69% are currently non-existent [5]. Consequently harmonized testing methods are essential to generate data for backsheet comparison and selection. For instance general testing procedures for polymeric materials are highly regulated by very well defined international standards so that databases like CAMPUS (Computer Aided Material Preselection by Uniform Standards) become possible. So the main objective of this paper is to characterize and to classify commercially relevant backsheets as to their material, laminate structure and basic optical and mechanical properties to lay the foundation for large-scale data collection and comparison.

2. Experimental

2.1. Selected backsheets films

To structure the great variety of commercially available backsheets materials a classification scheme was established based on the different polymeric materials involved in their build up. A summary of various currently used fluoropolymers and engineering thermoplastics is given in Fig. 2. Films based on fluoropolymers are

* Corresponding author.

E-mail addresses: klaus_jakob.geretschlaeger@jku.at (K.J. Geretschläger), gernot.wallner@jku.at (G.M. Wallner), joerg.fischer@jku.at (J. Fischer).

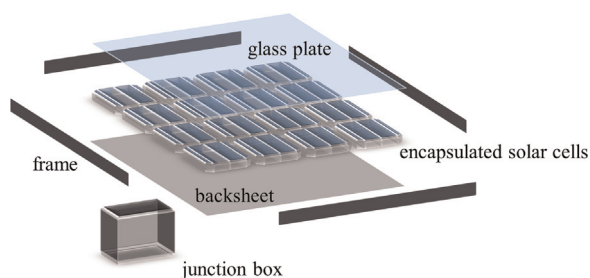


Fig. 1. Exploded view drawing of a photovoltaic module.

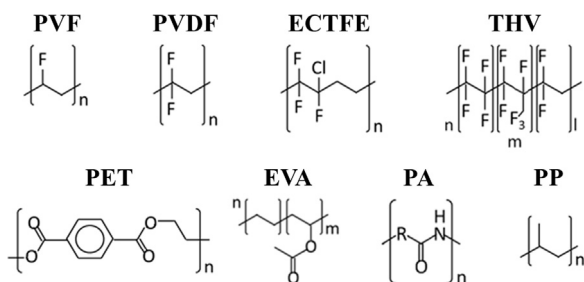


Fig. 2. Fluoropolymers and engineering thermoplastics.

Table 1
Investigated backsheets.

Code	Manufacturer	Tradename
TPT-1	Isovoltaic	Icosolar PPF 2442
TPT-2	Krempel	PTL 3 - 38/250
TPT-3	Krempel	PTL 3 HR 1000V
FP-1	Isovoltaic	Icosolar FPA 3572
FP-2	Krempel	PVL Akasol 1000 V
FP-3	Honeywell	Powershield PV 270
FP-4	3M	Scotchshield 17T
PET-1	Dunmore	Dun Solar PPE+ 1360
PET-2	Coveme	DyMat PYE 3000
PET-3	Isovoltaic	Icosolar APA 3552
PA-1	Isovoltaic	Icosolar AAA 3554

grouped into Tedlar-Polyester-Tedlar (TPT-backsheets) and single-Tedlar respective other non-Tedlar fluoropolymers (FP-backsheets). Backsheets based on engineering thermoplastics were categorized as polyethylene terephthalate core layer (PET-backsheets), polyamide core layer (PA-backsheets) and polyolefin core layer (PO-backsheets) [6]. The investigated backsheets are listed in Table 1 and are described as to class specific specimen code, manufacturer and the actual product tradename.

2.2. Structural characterization

To investigate the layer structure of the laminates representative sections of the various backsheets materials were embedded upright into acrylic resin and then wet polished to a smooth finish. An Olympus BX-61 light microscope was then used to measure the thickness of the individual layers. Identification of organic and inorganic components was achieved by application of a Horiba Scientific XploRA Raman confocal microscope. The spectral range between 100 and 3800 cm^{-1} was evaluated. A green laser at 532 nm and an infrared laser at 785 nm were used. Without any preparation the specimens were measured in multiple spots on both surfaces. For probing the individual layers the embedded laminates were characterized. To confirm the identity of the organic content in the backsheets materials a PerkinElmer FTIR Spectrum 100 infrared spectrometer providing a Universal ATR (attenuated total reflexion) sampling accessory was applied. For

probing the laminates inside and outside surfaces small sections were compressed against the detector crystal without any further preparation necessary. For the experiments conducted the detection window ranged from 650 to 4000 cm^{-1} . In case of EVA containing specimens also the vinylacetate (VA) content was determined by setting up a calibration curve from samples of known composition. Therefore the absorption was detected at 1238 cm^{-1} indicating the $\nu(\text{COO})$ stretching of the carboxyl unit and at 1465 cm^{-1} representing $\delta(\text{CH}_2)$ and $\delta_a(\text{CH}_3)$ deformation [7]. Then the ratio of these two values was plotted against the vinylacetate concentration of the calibration samples.

2.3. Thermal, optical and mechanical characterization

To characterize thermal transitions such as melting and decomposition temperature ranges and to determine the inorganic filler materials and pigments a PerkinElmer STA 6000 simultaneous thermogravimetric and calorimetric analyser was used. The heating was done from 30 to 995 $^{\circ}\text{C}$ at a rate of 20 $^{\circ}\text{C}/\text{min}$ and under a sustained flux of nitrogen at 20 ml/min. Specimens were prepared by weighing about 20 mg into lidless aluminum oxide crucibles. Optical properties between 250 and 2500 nm were characterized using a PerkinElmer Lambda 950 UV/VIS/NIR spectrometer combined with a 150 mm integrating sphere. Therefore small sections of the backsheets films were probed from both sides as to their reflectance and transmittance values. Absorbance was then calculated by subtracting reflectance and transmittance from unity. The directional normal-normal spectra were calculated by subtracting the measured normal-diffuse from the measured normal-hemispheric spectra. For weighting the spectral data the AM1.5 global solar irradiance source function (E_{λ}) was applied [8]. Therefore the wave length dependent irradiance function values were multiplied with the corresponding measured values and summed up for the entire spectral range. Finally this sum was divided by the global irradiance [9]. Mechanical properties such as Young's modulus and stress and strain at break were gained according to ISO 527 standards on a Zwick Roell Z 2.5 tensile testing machine at room temperature [10]. Specimens were prepared by punching 6 mm wide and 100 mm long stripes out of the material parallel to the machine direction. Traverse speed for secant modulus detection between 0.05% and 0.25% strain was 1 mm/min and beyond that and until break a rate of 50 mm/min was applied.

3. Results and discussion

3.1. Layer and material structure of the backsheets

The thickness values of the selected backsheets laminates ranged from 284 to 536 μm with a median value close to 350 μm . Microscopic images of representative backsheets from each category are given in Fig. 3. The TPT-backsheets revealed a symmetric structure in terms of dimensions and appearance. All surface layers were approximately 40 μm thick and had white color. The core layer however was colorless and about 260 μm thick. The FP-backsheets exhibited a 15 to 43 μm thick white outside layer. The three layered specimens (FP-1, FP-2 and FP-3) had colorless cores of 131 to 270 μm thickness. The four layered laminate (FP-4) however had two core layers. Oriented towards the outside a 53 μm thick layer of reduced whiteness was observed. Inwardly a white 77 μm layer was detected. In the triple layer laminates the inside layers were 30 to 123 μm thick and white. In the quadruple layer assembly however a massive 363 μm thick and colorless inside layer was noticed. The PET-backsheets revealed 143 to 262 μm thick colorless core layers. The asymmetrically built

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