Chapter 1 Description and control of solar cell protection material for quality assurance of a photovoltaic panel

Capítulo 1 Descripción y control del material de protección de las celdas solares para el aseguramiento de calidad de un panel fotovoltaico

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Abstract

Global warming and climate change coincide in their main causes, the massive emission of greenhouse gases, which retain heat in the atmosphere and on the earth's surface through the so-called greenhouse effect. The generation of electricity by means of fossil fuels is an important emitter of greenhouse gases (CO_2, CH_4, N_2O), and halogenated compounds containing F, Cl, and Br. With the purpose of contributing to the construction of viable solutions to the current energy situation of the country and in the foundation of a sustainable future, the use of solar energy for the generation of electricity by means of solar panels represents an option. The purpose of this study is to describe and control the solar cell protection material Ethylene-Vinyl-Acetate (EVA), as a contribution to the Quality Assurance of solar panels, since the function of this material is essential for the protection of solar cells, which are a vital part of the solar panel. The tests performed were: Gel content, adhesion test, and durability tests. The results obtained were within specification according to IEC 61215. From this work it is concluded that it is important to continue testing the whole process and components of the solar panels in order to guarantee the useful life of the finished product, as well as to contribute to sustainable development.

Control, Ethylene vinyl acetate, Solar cells, Solar panel

Resumen

El calentamiento global y el cambio climático coinciden en la principal de sus causas, la emisión masiva de gases efecto invernadero, los cuales retienen el calor dentro de la atmósfera y sobre la superficie terrestre a través del denominado efecto invernadero. La generación de electricidad por medio de combustibles fósiles es un importante emisor de gases efecto invernadero (CO_2, CH_4, N_2O), y compuestos halogenados que contienen F, Cl, y Br. Con el propósito de contribuir en la construcción de salidas viables a la situación energética actual del país y en la cimentación de un futuro sostenible, el uso de la energía solar para la generación de energía eléctrica por medio de los paneles solares, representa una opción. Este estudio tiene como finalidad describir y controlar el material de protección de las celdas solares Etilen-Vinil-Acetato (EVA), como contribución al Aseguramiento de Calidad de los Paneles solares, ya que la función de dicho material es primordial para la protección de las celdas solares, las cuales son parte vital del panel solar. Los ensayos realizados fueron: Contenido en gel, Prueba de adherencia, y Ensayos de durabilidad. Los resultados obtenidos estuvieron dentro de especificación conforme a la Norma IEC 61215. De este trabajo se concluye que es importante seguir realizando ensayos en todo el proceso y componentes de los paneles solares para poder garantizar la vida útil del producto terminado, así como contribuir al desarrollo sustentable.

Control, Etilen vinil acetato, Celdas solares, Panel solar

1.1 Introduction

Global warming is a current problem, which consists of an increase in the earth's temperature, reflected in the oceans and the atmosphere, caused mainly by the emission of greenhouse gases emitted by human activity.

Global warming and climate change coincide in their main causes, the massive emission of different greenhouse gases or gases that retain heat in the atmosphere and on the earth's surface through the so-called greenhouse effect.

The greenhouse effect is a natural process by which the heat from the Sun is retained in the Earth's atmosphere thanks to the layer of greenhouse gases found in it. These gases in normal quantities maintain the temperature of the planet at approximately 33ºC above what it would be if they did not exist, so the planet would be too cold for life to develop on it. Moreover, the greenhouse effect is now becoming so intense due to our emissions that it is beginning to have serious repercussions on the environment. Currently, developing countries depend primarily on crude oil to meet their energy needs, and for more than two-thirds of these, dependence is vital as it covers about 70% of needs.

In order to reduce environmental pollution and provide solutions to such problems, in 1993 Mexico joined the international effort to mitigate global climate change by acceding to the United Nations Framework Convention on Climate Change and ratifying the Kyoto Protocol in 2000. Mexico also supported the Latin American and Caribbean Initiative for Sustainable Development at the World Summit on Sustainable Development in Johannesburg, South Africa, in which the goal of implementing the use of at least 10% renewable, non-polluting energy of the total energy percentage by the year 2010, according to data from the Ministry of Energy.

Renewable energy

Renewable energies are those that are produced continuously. All renewable energy sources (except tidal and geothermal) ultimately come from the sun. Its energy causes the differences in atmospheric pressure that give rise to winds, a source of wind energy. It also causes the evaporation of water which then precipitates to form rivers, a source of hydropower. Plants and algae use the sun for photosynthesis, the source of all organic matter (or biomass) on Earth. Finally, the sun is used directly as solar energy, both thermal and photovoltaic. These sources are inexhaustible on a human scale, although in the case of biomass, this is the case as long as natural cycles are respected.

Geothermal energy. The Earth's heat is harnessed to obtain hot water, steam or electricity from groundwater. New technologies even make it possible to exploit hot rock deposits. This energy is used in areas with high geothermal activity, such as Iceland.

Biomass energy. Organic plant or animal materials are burned or chemically processed to produce fuels (such as biodiesel), heat and electricity. It has been the most widely used energy by humans and in many poor regions of the world it is still the main source of energy.

Hydropower. River water has been used for centuries to power machinery, for example, to grind corn. Today, this energy is mainly used to generate electricity. Hydroelectric technology is one of the most developed, cost-effective and reliable.

Ocean energy. The swaying of water from tides or waves, ocean currents, even the temperature difference between the water at the sea surface and the deep sea, could also be used to generate energy. At present, however, there is no commercially viable system of this type.

Wind energy. Wind has for centuries been captured by sails and blades for transportation and mechanical work. Modern wind turbines allow electricity to be obtained cleanly and efficiently. These machines can dump large amounts of energy into the grid or meet small demands.

Despite efforts to grow and modernize the electricity sector, electricity still does not reach nearly millions of people in rural areas. The growing demand for electricity in Mexico, along with the constant emission of pollutants into the atmosphere from the burning of fossil fuels, has also increased interest in the exploitation of alternative sources of renewable energy, which can help solve the demand for electricity without the problems of pollution.

One such alternative source is solar energy. In this Chapter, relevant topics on the description and control of the protection material of a Solar Panel are addressed, which are structured in seven sections named as follows:

Section 1.2 Background of solar energy.

Section 1.3 Structure of a solar panel

Section 1.4 Solar Cell Operation

Section 1.5 General information about the protective material of the solar cell (EVA)

Section 1.6 Function of the solar cell's protective material (EVA)

Section 1.7 Characteristics of the protective material (EVA).

Section 1.8 Tests for the control and quality assurance of the protective material (EVA) in the solar panel.

One such alternative source is solar energy. In this Chapter, relevant topics on the description and control of the protection material of a Solar Panel are addressed, which are structured in 7 sections named as follows:

1.2 Background on solar energy

Photovoltaic solar energy directly transforms sunlight into electricity using a technology based on the photovoltaic effect.

In general, solar energy can be described as energy that is received from sunlight and converted into electrical energy for human use. It is more economical and feasible, since the sun is within everyone's reach, on the other hand, solar panels are elements built with the main purpose of converting solar energy into electrical energy. They are constructed from an element called silicon, which participates in the process of creating electrical energy from sunlight. Solar energy can have a direct or indirect impact. A solar panel on cloudy days, contrary to popular belief, can produce energy perfectly well.

The photovoltaic effect was first discovered in 1839 by the French physicist Alexander-Edmond Becquerel. His studies were fundamental to the development of the use of photovoltaics.

1.2.1 Photovoltaic effect

The photovoltaic effect; converts the light energy carried by photons of light into electrical energy capable of driving electrons fired from the semiconductor material through an external circuit.

Sunlight is made up of photons or energetic particles. These energetic particles are of different energies, corresponding to the different wavelengths of the solar spectrum.

When photons hit a photovoltaic cell, they can be reflected or absorbed, or they can pass through it. It is the absorbed photons that transfer their energy to the electrons in the atoms of the cells.

To produce a useful electric current, the released electrons must be extracted from the material before they recombine with the "holes". One way to achieve this is to introduce chemical elements into the semiconductor material that help produce excess electrons and holes. These elements that significantly alter the intrinsic properties of semiconductors are called dopants and the process of their incorporation into the semiconductor is called doping.

The semiconductor material does not store electrical energy at any time, the only thing it does is to generate it, or rather, transform radiant energy only when it affects it. Not all photons behave in the same way when producing electricity by photovoltaic effect, some frequencies are more suitable than others to produce this effect depending on the types of semiconductor materials used.

Spectral response is a measure of the efficiency with which a photovoltaic device converts light energy into electrical energy for a given frequency of incident light.

For example, In a monocrystalline silicon cell, such conversion efficiency is only significant for wavelengths between 350 and 1100 nanometers, with a maximum around 800 nanometers, while for amorphous silicon the range is from 350 to 800 nanometers, with a maximum around 520 nanometers. (Obaya J, 2002).

1.2.2 Solar panels

A single cell is not capable of providing a voltage that can be used in practice, only generating a voltage of a few tenths of a volt (usually around half a volt for silicon cells) and a maximum power of one or two watts. To obtain adequate voltages and power, a number of cells must be connected in series to produce voltages of 6, 12 or 24 volts, which are accepted in most applications. This set of interconnected cells, assembled and protected against external agents, is called solar panel or photovoltaic module.

The cell connection process is automatic and is carried out by means of special welds that join the front face of one cell to the back face of the adjacent one. Between 30 and 40 cells, depending on their characteristics, are needed to produce a nominal 12 volt panel.

1.2.3 Principle of operation

Theoretical principles of operation. Some of the photons, which come from solar radiation, strike the first surface of the panel, penetrate it and are absorbed by semiconductor materials, such as silicon or gallium arsenide. The electrons, atomic sub-particles that form part of the exterior of the atoms, and which are housed in orbitals of quantized energy, are hit by the photons (they interact) freeing themselves from the atoms to which they were originally confined. This allows them to subsequently circulate through the material and produce electricity. The complementary positive charges that are created on the atoms that lose electrons (similar to positive charge bubbles) are called holes and flow in the opposite direction of the electrons in the solar panel.

It should be noted that, just as the flow of electrons corresponds to real charges, i.e., charges that are associated with real mass displacement, the voids are actually charges that can be considered virtual since they do not involve real mass displacement. (Fernandez, M. 2010).

1.2.4 Types of commercial photovoltaic panels

The different types of panels can be classified according to different criteria:

- According to the type of cells they contain. Thus, we speak of monocrystalline, polycrystalline and amorphous panels.

- According to the type of material the cells are made of: silicon panels, gallium arsenide, cadmium telluride, silicon film, etc.

- Considering the power it is capable of producing. There are mini-panels with as little as 1 W or 2 W of power, such as those used to keep a car battery charged, and we can also find large panels with power ratings of up to 300 W. The most common power ratings that can be found in the market are: 5W, 10W, 20W, 35W, 40W, 60W, 75W, 100W and 175W.

- Depending on the voltage or voltage, the maximum potential difference that a panel can provide is Voc (Open Circuit Voltage), although the effective working voltage is always lower, depending on the number of cells, we are talking about 6 panels of 12 V or 24 V. The most used are those of 12 V, coinciding with the voltage of the most used accumulators.

- Depending on whether they take advantage of radiation on one side or on both sides. The bifacial panels, developed by the Spanish A. Luque, are also capable of capturing the reflected radiation (albedo) from the back of the panel, installing them on a white surface, being able to obtain an increase in useful power of about 20%. (Fernandez, M. 2010).

1.2.5 Ethylene vinyl acetate (EVA) material

The EVA is adhered to the cells, but it is usually reinforced as the rear base of the module for greater safety with the material called TPT (Tedlar-PET-Tedlar), which consists of a three-layer sandwich laminate formed by a layer of polyester film between two layers of PVF. (Marcillo Proaño, W. and Moreno Garrido, F. 2008).

1.2.6 Types of cells

Monocrystalline cells: are formed by sections of a single silicon (Si) crystal.

Polycrystalline cells: when they are formed by small crystallized particles.

Amorphous cells: when the silicon has not crystallized.

The efficiency of the cells is higher the larger the crystals are, but they also increase in weight, thickness and cost. The efficiency of monocrystalline cells can reach 20% while that of amorphous cells cannot reach 10%, although their cost and weight are much lower.

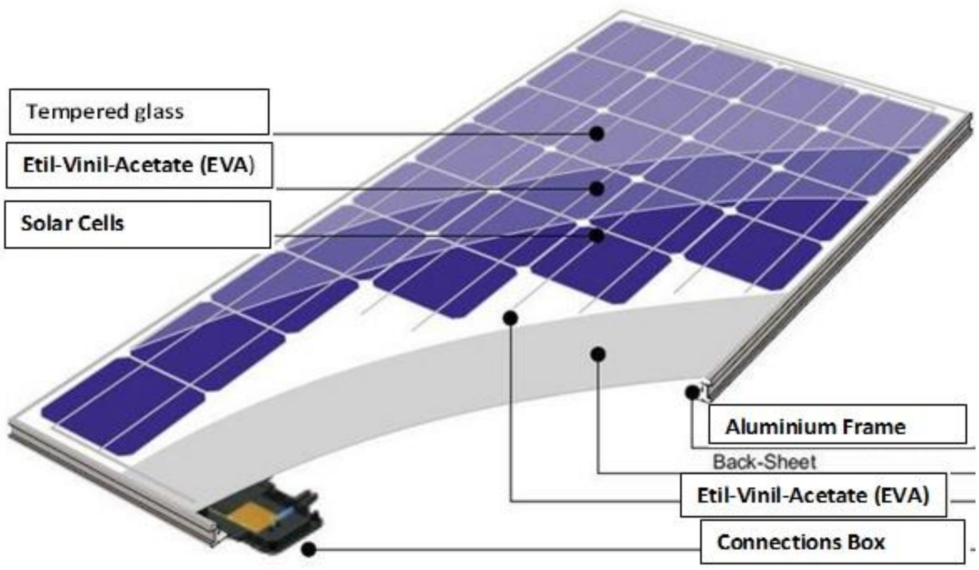
1.2.7 High-performance polycrystalline solar panels (photovoltaic)

To provide the solar cells with maximum protection under the most adverse environmental operating conditions, they are encapsulated between a tempered glass cover and an ethylene vinyl acetate (EVA) cover with polyvinyl fluoride and a backing sheet. The laminate is mounted on an anodized aluminum frame to provide structural strength and ease of installation.

1.3 Structure of a solar panel

The structure of a crystalline cell solar module generally consists of the following parts: an aluminum frame, structured glass, interconnected solar cells, EVA protection material, the back sheet, the frame and the junction box. Fig. 1.1. There is also the option of manufacturing another type of module. In this case, a second glass plate is laminated in place of the back sheet.

Figure 1.1 Parts of a solar panel



Source: Own elaboration

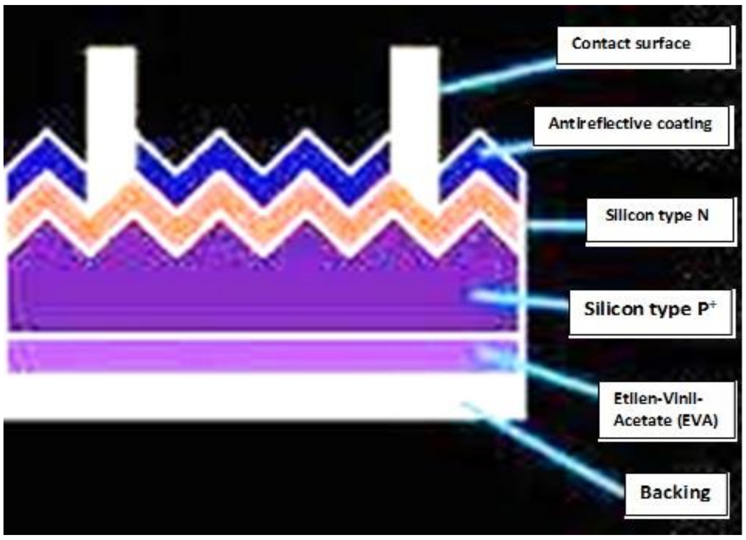
1.3.1. Structured glass

Soda, lime and silica tempered glass with a thickness between 3 and 4 mm, with low iron content. It has very good solar radiation transmission and provides protection against atmospheric agents and impacts. The outer surface of the glass is anti-reflective and is treated to prevent the retention of dust and dirt. The inner surface is generally roughened, which allows good adhesion with the cell encapsulating material Ethylene-Vinyl-Acetate (EVA), as well as facilitating the penetration of solar radiation.

1.3.2 Solar cell

Solar cells are direct conversion devices that directly transform the sun's energy into electrical power (DC) without any intermediate processes. Since power P=IV, then it is necessary to understand how current I and voltage V are generated in the cell. In turn, I is the result of charges moving in a given direction. The charges are already in the material, but in semiconductors they are in a bound state. Under the action of light, the charges become free, capable of forming a current. The charges are directed in a certain direction to form a current thanks to the action of the electric field created in the cell. Fig. 1.2.

Figure 1.2 Layers of a solar cell: (1) Contact surface, (2). Anti-reflective coating, (3). N- type silicon, (4). Silicon type P+, EVA (5), Backing (6)



Source: Own elaboration

The physical structure, or atomic arrangement, of semiconductors can be divided into three groups: single crystal, polycrystalline and amorphous. The single crystal structure is characterized by a periodic arrangement of atoms obtaining a three-dimensional geometric shape of a parallelepiped. Such is the case of silicon which shares each of its four valence electrons in a covalent bond with each neighboring silicon atom, the solid, therefore, consists of a basic unit of 5 silicon atoms, the original atom plus the four atoms with which it shares its valence electrons.

1.3.2.1 Components of the cell

1.3.2.1.1 Silicon plate doped with phosphorus and boron to obtain a positive and a negative side

1.3.2.1.2 Anti-reflective layer in the form of cones or pyramids that capture the sun's rays more easily

1.3.2.1.3 Grids or fingers. These are responsible for collecting the charges produced in the solar cell

1.3.2.1.4 Bussbar

The Bussbar is the main collector, it passes in the negative and positive part of the cell, where the ribbon is joined to form chains of cells Fig. 1.3.

Figure 1.3 Cell strings

Source of reference: Own elaboration

1.3.2.1.5 EVA

Two layers of Ethyl-Vinyl-Acetate (EVA) are used between the cell matrix. This copolymer is in direct contact with the cells in such a way that it protects the connections between them and provides resistance against vibrations and impacts. In addition, it allows the transmission of solar radiation and is not degraded by ultraviolet radiation.

1.3.2.1.6 Back-Sheet (Tedlar)

This material is regularly used as a three-layer laminate. The outer layer is polyvinyl fluoride (PVF, commercially called TED-LAR). This, together with the front cover, protects the module from moisture and other atmospheric agents, but does not electrically insulate it; a second layer of polyester (Polyethylene Terephthalate) is used for this purpose. Another layer of TEDLAR is used for the internal part. This plastic composite sheet is opaque in nature, usually white in color to reflect the sunlight that the cells do not store onto the roughened back side of the front cover, which reflects the light back into the cells.

The modules are produced by first connecting the individual cells to form strings. Fig. 1.3. These are then reconnected to each other and then laminated by means of equipment called a laminator with all components placed on top of each other except the frame. The purpose of the lamination process is to fix the EVA to protect the cells from external factors and the environment for as long as possible.

1.3.3 Solar panel applications

- Microwave and radio repeater stations.
- Electrification of villages in remote areas.
- Medical posts in rural areas.
- Power for cottages.
- Emergency communication systems.
- Environmental and water quality data monitoring systems.
- Lighthouses, buoys and maritime navigation beacons.
- Water pumping for irrigation systems, drinking water in rural areas and livestock watering troughs.
- Beacons for aeronautical control and signals.
- Cathodic protection systems.
- Desalination systems.
- Signals in railway networks.
- Recreational vehicles.
- Recreational vehicles and boats.
- Railway signalling.

Solar panels are undoubtedly one of the best modern inventions, as well as being probably the invention that contributes the most to the ecology. Solar panels are modules that use the energy that comes from solar radiation, and there are several types, such as those for domestic use that produce hot water or photovoltaic solar panels that produce electricity. Photovoltaic solar panels are composed of cells that convert light into electricity. These cells take advantage of the photovoltaic effect, whereby light energy produces positive and negative charges on two nearby semiconductors of different types, thereby producing an electric field with the capacity to generate current. Photovoltaic solar panels can also be used in solar vehicles. The standardized parameter to classify their power is called peak power, and corresponds to the maximum power that the module can deliver under standardized conditions, which are:

Radiation of 1000 W/m², Cell temperature of 25 °C (not ambient temperature). (Fernandez, M. 2010).

1.4 Solar Cell operation

1.4.1 Structure

Photovoltaic cells are made of semiconductors. Semiconductors are elements that have a very small electrical conductivity, but superior to that of an insulator. The most commonly used are those made of silicon. When the sun's rays strike the cells, the P - N junction of its semiconductors together with its conductive metal helps to produce energy. In this junction, the P-N junction are positive and negative charges that help to produce electric current, due to a potential difference that is created when the cell is illuminated.

1.4.2 Operation of a solar cell

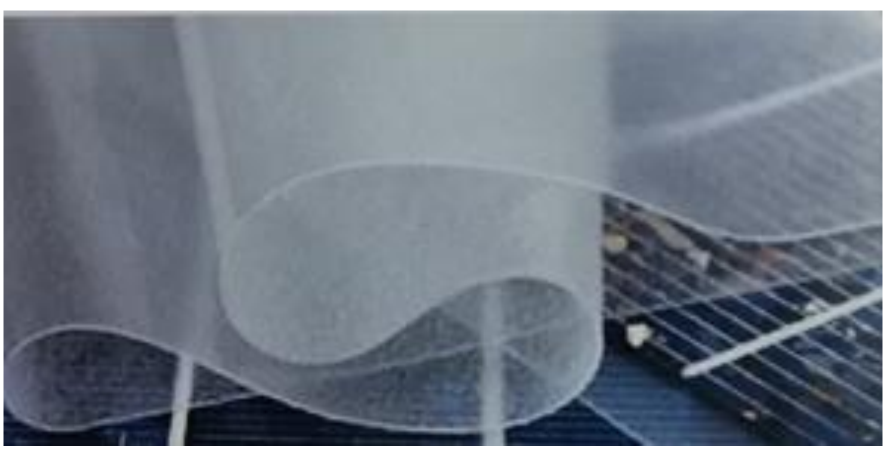
A solar cell is generally composed of silicon, a semiconductor material, which becomes electrically conductive when power is supplied. For this reason, solar cells are predominantly made of silicon, as this material is more than sufficient and has been the most technologically researched to date. There are crystalline solar cells and thin-film solar cells. Crystalline solar cells are divided into polycrystalline and monocrystalline.

The difference between the two types of cells lies in the cell structure. Monocrystalline solar cells consist of a single crystal, while polycrystalline solar cells consist of many small individual crystallites. Monocrystalline solar cells have a higher degree of efficiency, but are more expensive due to the much more complex production. After cutting each of the so-called wafers made from a block of silicon, they are purely and exclusively positively or negatively doped with the addition of foreign atoms, which makes them conductive. The stronger the doping, the more charge carriers are available and the higher the current flow. If two differently doped layers are trapped together, a PN junction is created which creates an electric field.

1.5 Overview of the EVA solar cell protection material

The coating material is one of the most important components of a solar module today and must meet many requirements. Fig. 1.4.

Figure 1.4 Roll of Ethylene-Vinyl-Acetate (EVA) Material



Source: Own elaboration

It is mainly used for bonding and encapsulating solar cells and is intended to protect them against the effects of long-term weathering. The encapsulated protective material used must have the best possible properties against water vapor and oxygen; otherwise, the metal contacts and interconnections may degrade, and the solar module will become unusable. The protective material may also show colour changes (yellowing), due to excessive absorption of oxygen or water vapor and thus cause a loss of transmission.

A high degree of transmission is very important for the material used, since the transmission of the material is directly related to the generation of electricity. The higher the transmission of a material, the lighter the cell can absorb and convert it into electricity. In addition, a good protective material must have a relatively high thermal resistance, as well as good thermal conductivity, since modules can heat up to 90 degrees in direct sunlight. The material must be able to withstand that temperature; the better the thermal conductivity of the encapsulation material, the better the heat can be dissipated. The encapsulation material also ensures greater stability of the module and serves as protection in case of glass breakage. The material used as solar cell protection must, among other things, have a high level of stability against UV radiation, since short-wave radiation can yellow the material and reduce transmission Fig. 1.5, Due to the different materials incorporated with different coefficients of thermal expansion, the protection material must compensate for the stresses occurring so that no cell breakage or damage to the module occurs. All the properties listed here must be fulfilled with a good material in order to produce durable and efficient modules, it should be mentioned that ethylene vinyl acetate is a thermoplastic material.

Figure 1.5 Yellowish EVA material due to degradation

Source: Own elaboration

1.5.1 Introduction to plastics

Plastics are materials consisting of organic or semi-organic macromolecular polymers. They are characterized by an extraordinary range of physical and chemical properties and have therefore become established in almost all areas. In order to use a polymer substance as a material, the polymer must be prepared with additives such as processing aids, stabilizers, pigments and fillers. As a result, mechanical strength, thermal stability or chemical resistance can be individually adapted as required. Plastics are manufactured in a wide variety of types and can now be processed with high precision. In addition, plastics have the advantage over metal, wood and other materials that they can be produced with less energy. Many different plastics technology processes can be used in the preparation and post-processing of plastics, which makes processing simpler and more economical in many respects. In addition, many processes are run simultaneously during material forming, which enables high throughput in production and thus makes the products very economical. Due to the low specific weight of plastics, they are also very suitable as packaging and transport material. In addition, there are very good recycling options for plastics, especially thermoplastics. Due to the many possible uses and the relatively low prices, plastics have established themselves as the highest performing products at affordable prices. Manufacturing costs are essentially determined by material costs. Therefore, an appropriate choice of materials and material-saving construction is economical.

The use of ecologically sensitive plastic is particularly important. In addition to all the advantages, there are some disadvantages that cause problems and risks. Non-renewable raw materials, such as oil or natural gas, are used in the production and processing of plastics, which are harmful to the environment. Since many plastic products today are disposable items, poisonous gases and toxins arise in the case of multiple combustion, especially due to plastics.

Supply of plastics. Plastics consist of many monomers bonded together to form a polymer.

1.5.2 Classification of plastics

Plastics can be classified into certain classes of plastics according to the structure and binding mechanism of the macromolecules. A distinction is made between the following macromolecular types straight chain molecules

Branched-chain molecules

Weakly cross-linked chain molecules

Strongly cross-linked chain molecules

Based on these types of molecules and the resulting binding mechanism, plastics can be divided into the following categories:

1.5.2.1 Thermoplastics

Thermoplastics, also called plastomers, are plastics whose macromolecules form linear or branched molecular chains. These are connected to each other by weak physical binding forces. The more branches the molecules in the chain have, the closer they can be placed next to each other and therefore have greater binding forces. This process of placing them very close to each other and thus having greater binding forces is called crystallization.

However, due to the long molecular compounds, it is not possible to achieve a complete crystalline structure with plastics, which is why we also speak of semi-crystalline thermoplastics. Due to the partially crystalline area of thermoplastics, they are never completely transparent when not colored. This is due to the different scattering of light at the crystal edges.

1.5.2.2 Elastomers

Elastomers are dimensionally stable, but elastically deformable plastics. The glass transition point is below room temperature. Examples of elastomers are: Tires, rubber or gaskets. Elastomer macromolecules have weak cross-linking, which makes them particularly elastic and flexible.

1.5.2.3 Duroplastics or thermosets

Thermosets, which are also known as thermosets, like elastomers, are crosslinked plastics. However, compared to elastomers, thermosets have significantly more crosslinking points and are therefore much harder and tougher. They are very hard and brittle at room temperature and, like elastomers, cannot melt or dissolve.

Cross-linked plastics retain their rigidity even at higher temperatures, which is why they are also called temperature-resistant. At a certain temperature (decomposition temperature), thermosets and elastomers decompose.

1.5.3 Polymerization

In polymerization, a chain reaction takes place, in which unbundled molecules (monomers) are knotted into macromolecules and then form a polymer. A polymerization can only take place if the monomers contain double bonds.

For all types of polymerization, the reaction principle is identical and can be divided into the following sections: Initial reaction. Growth reaction, chain transfer, termination reaction. A distinction is made between the types of polymerization taking into account the reactive particles and can be divided into the following categories: radical polymerization, ionic polymerization, polymerization with transition metal compounds (catalysis).

The most widely used and proven material in the production of photovoltaic modules to date is Ethylene-Vinyl-Acetate (EVA), which is a thermoplastic material.

1.5.4 Properties of thermoplastic polymers

A defining characteristic of thermoplastic polymers is that they can be heated from the solid state to the viscous liquid state and, upon cooling, return to the solid state; furthermore, this cooling cycle can be applied many times without degrading the polymer. The reason for such behavior is that thermoplastic polymers consist of linear (branched) macromolecules that do not crosslink when heated. In contrast, thermosets and elastomers undergo a chemical change when heated, which causes their molecules to cross-link permanently. In fact, thermoplastics deteriorate chemically with repeated heating and cooling. In plastics molding, a distinction is made between new or virgin material and plastics that have been previously molded and have undergone thermal cycling (*e.g.* scrap and defective parts). For some applications only virgin material is accepted. Thermoplastic polymers also degrade progressively when subjected to temperatures below the conversion temperature from the crystalline state to an amorphous state (tm), this long-term effect is called thermal aging and involves slow chemical deterioration. Some of the thermoplastic polymers are more susceptible to thermal aging than others, and for the same material, the rate of deterioration is temperature dependent.

1.5.5 Thermoplastic Ethylene-Vinyl-Acetate (EVA)

This thermoplastic is known as EVA, a compound based on a copolymer of ethylene with vinyl acetate; this copolymer has elastic properties, which are enhanced by the action of peroxides. The incorporation of the vinyl acetate monomer produces a reduction in the crystallinity of the material, so the properties of ethyl vinyl acetate (EVA) depend largely on the molecular weight and the vinyl acetate content.

The main property of EVA is shock absorption; its main component is latex. Latex is a resin obtained from more than one hundred species of shrubs or oil, which becomes sticky with heat and easily breaks down with cold, so after being initially treated in plates, ethyl acid, vinyl and acetate must be added to obtain EVA (Marcillo Proaño, W. and Moreno Garrido, F. 2008).

1.5.6 EVA composition

The vinyl acetate content in the copolymer varies from 5% to 50%, although for optimal applications the vinyl acetate content should be in the range of 5% to 20%; with 30% to 50% vinyl acetate, it has elastomeric properties.

1.5.6.1 Vinyl acetate content in EVA

The properties of EVA are highly dependent on the molecular weight and vinyl acetate content. Increased vinyl acetate helps to:

- Decrease the crystallinity of EVA.
- The density of EVA increases.
- EVA becomes clear.
- EVA becomes more flexible at low temperatures.
- EVA becomes more impact resistant.
- If the vinyl acetate content is higher than 50%, EVA is amorphous and transparent.
- The higher the percentage of vinyl acetate (VA), the material will exhibit greater expansion with heat.

1.5.6.2 Properties of EVA

- Excellent optical properties;
- High flexibility at low temperatures;
- Good puncture and impact resistance;
- High elasticity and easy processing;
- Good bending strength;
- Low shrinkage temperature;
- Excellent noise insulation;
- Good vibration absorption properties;
- Good resistance to ultraviolet light;
- High mechanical strength in relation to its density;
- Excessive plasticity (when stretched they do not recover). (Marcillo Proaño, W. and Moreno Garrido, F. 2008).

1.6 Role of EVA as a protection material in Photovoltaic Modules

EVA completely covers the cells, preventing the entry of micro or nano quantities of air, as well as the presence of water (humidity) in the cell.

It serves as an electrical insulator, a material that protects the cells (cells) from exposure to the environment and chemical materials, resistant to vibration and also to mechanical shock, the panel is subjected to climatic changes and temperature that can vary from below zero degrees. above 50 ° C, in addition to the degrading effects of ultraviolet radiation, it is stable at high temperatures (180 ° C for short periods of time). (Marcillo Proaño, W. and Moreno Garrido, F. 2008).

1.7 Characteristics of EVA protection material

Ethylene vinyl acetate is a thermoplastic polymer, it is recyclable, incinerable, easy to handle, moldable and non-toxic, it is manufactured in sheets of various thicknesses and sizes, easy to glue, simple to cut, can be painted, washed and has minimal or no water absorption capacity, is resistant to degradation by sunlight, resists chemical attacks and absorption of solvents, in addition to offering its degree of solar energy transmittance, it is quite useful to cover the cells or cells, characteristics for which it is used in photovoltaic modules or solar panels. (Obaya J, 2002).

Ethylene vinyl acetate (EVA) is a copolymer of ethylene and vinyl acetate with relatively strong branches and low crystalline proportions. In the production of vinyl acetate, ethene, oxygen and acetic acid are reacted in a gas-phase process in the presence of a palladium catalyst added to the vinyl acetate. This catalytic addition method, also used by Wacher Very, is a widespread process in the chemical industry.

The vinyl acetate content in EVA copolymers can influence the properties for certain applications. The following properties decrease with increasing VAC content: stiffness, toughness, dimensional stability in heat, electrical insulation values, chemical resistance, electrostatic charge. On the other hand, the following properties increase with increasing VAC content: impact resistance, light transmission and gloss, stress cracking and weathering resistance.

The vinyl acetate content for solar module films suitable for EVA should be in the range of 28-33%. The Etimex brand films used by Scheuten Solar have certain properties that are particularly suitable for applications in the solar sector and have been established over the years. The films have a melting range between 60 and 110°C and can be processed very well under vacuum. At temperatures above 110°C, the molecules cross-link to form a transparent, elastic and heat-resistant layer that protects the modules from the effects of weathering for a long time.

However, working with EVA requires great care. For example, crosslinking does not start at a certain temperature, but rather over a wide temperature range. This means that an exact process time must be determined for each lamination process at a given temperature. Because sensitive webs occur again and again below or above the bonds, they have a negative effect on the properties of the module. therefore, an extraction is carried out to determine the gel content at regular intervals, which provides information on the crosslinking or degree of branching of the material. A good network should be in the range of 80-95% gel content. The short shelf life of films in air is also an issue. After about 4 hours in air, the films become unusable because important additives diffuse out and the necessary adhesion to the glass and subsequent film can no longer be guaranteed. Ethylene vinyl acetate can only be melted once and cannot be processed further after crosslinking, which offers poor repair options in the production of solar modules. Several embedding materials, especially from the field of thermoplastic elastomers, have been able to solve these problems and can be used as an alternative material in addition to EVA. Polymers are still rarely or not at all used in solar module production, so there is very little experience in h The EVA position is bonded to the cells, but it is also often used as a post-module base for added security with the material called TPT (Tedlar-PET-Tedlar) which consists of a three-layer sandwich laminate made of a layer of polyester film between two layers of PVF. (Marcillo Proaño, W. and Moreno Garrido, F. 2008).

1.8 Tests for the Control and Quality Assurance of the Protective Material (EVA) in Solar Panels

Methodology

1.8.1 Gel content

This gel content test is intended to determine the amount of vinyl acetate present in the Ethylene-Vinyl-Acetate, which is directly related to the resistance of the material. This test tests the resistance of the encapsulation layer material of the module, ensuring that the current conduction pathways of the cells are hermetically isolated from the elements.

In this test the content was determined in five different points of the module to obtain an average of the gel content of the whole material, for this purpose the following activities were carried out:

1.8.1.1 A temperature of 105 ° C was set in the Memmert Stove.

1.8.1.2 5 Glass flasks with their respective lids and 5 Whatman Brand # 51 filter papers were placed in the oven for 2 hours.

1.8.1.3 After 2 hours, the flasks, lids and filter papers were removed from the oven.

1.8.1.4 The filter papers were placed in the desiccator.

1.8.1.5 The flasks with their respective lids were placed in a clean place for later use.

1.8.1.6 5 Samples of 10x10 cm were cut out of the laminated EVA.

1.8.1.7 1.00 gram of EVA (W1) was weighed from each sample.

1.8.1.8 100 ml of toluene was prepared for each sample (by dissolving 0.0865 grams of BHT in 100 ml of toluene).

1.8.1.9 Each EVA sample was placed in a bottle with 100 ml of the prepared toluene solution, and the bottles were capped.

1.8.1.10 The flasks were placed in the oven at 60 ° C (± 5) for 24 hours.

1.8.1.11 The flasks were removed from the oven and their respective lids were removed and allowed to stand for 1 hour.

1.8.1.12 Each filter paper was weighed and the weight was recorded as (W2).

1.8.1.13. In the fume hood area, a glass funnel was placed over a 1000 ml Erlenmeyer flask and filter paper was placed over the funnel and the samples were filtered.

1.8.1.14. It was put to a temperature of 105 ° C in the oven and the samples were placed with the filter paper and allowed to dry to constant weight.

1.8.1.15. Each filter paper was weighed with the sample residue and the weight (W3) was recorded.

1.8.1.16 The percentage of gel content was calculated with the following formula:

$$\% \text{ gel content} = w3 - w2 / w1 \; X \; 100 \quad (1)$$

1.8.2 Adhesion test

The adhesion test measures the adhesion between individual materials and is given in N / cm. The adhesion should be at least 25 N / cm in all tests and should be distributed as evenly as possible throughout the laminate. The adhesion of the protective material must have on the one hand, a good adhesion to the glass and, on the other hand, a good reflection and weather resistance.

This test was carried out using equipment (dynamometer), which separates the bus tape from the silicon cell vertically and records the force versus distance across the bar when the cable (tape) is pulled from the bottom upwards. of the cell. Fig.1.6. It is used to measure how hard the solder penetrated the cell and defects such as under soldering or over solder penetration can be detected.

Figure 1.6 Dynamometer for adhesion test

Source: Own elaboration

1.8.3 Durability tests

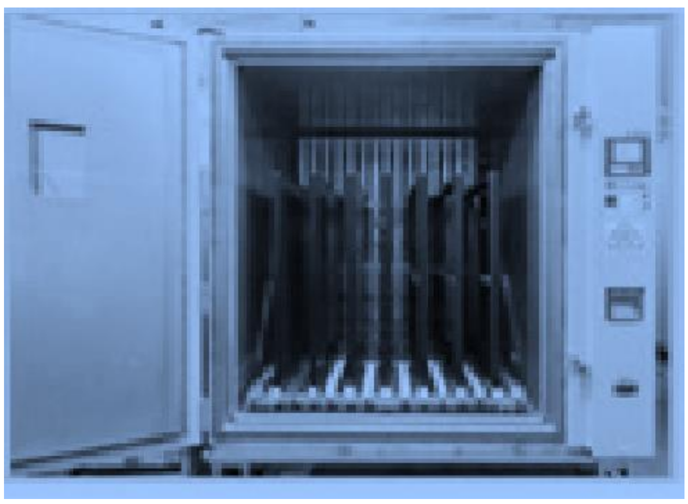
1.8.3.1 General

Solar panels must be tested with durability tests, which are intended to provide information on the useful life of the panel when it is in operation, since it will be exposed to the elements, sudden climatic changes (temperature, humidity, salt spray, dew, etc.), and environmental agents of the place where it is installed.

IEC and JIS standards stipulate that the modules must be tested for inclusion in an environment with a temperature of 85°C and a humidity of 85, they also require that the modules must be tested through 10 cycles of temperature fluctuations between -40°C and 85°C (where a cycle lasts 24 hours or less and the humidity is 85% and the temperature is 85°C).

The hot and humid climate is difficult not only for people, but also for solar modules. Prolonged exposure to high temperature and high humidity can accelerate the degradation of materials used in solar modules and can result in insulation failure or reduced electrical output [Kahtris R. (2011)]. In this test, solar modules are placed inside a heat and humidity test chamber. Figure 1.7. The electrical output of the modules and the harmful effects on them are carefully controlled. A dew condensation and freeze dew test is also performed in recognition of the fact that geographic areas susceptible to high temperatures and high humidity contents are also often prone to dew and frost condensation induced by temperature changes. Between day and night. In this test, dew and frost condensation is generated inside the test chamber, and the electrical output and any effects on the materials are monitored.

Figure 1.7 Thermal shock test chamber



Source: Own elaboration

1.8.3.2 Testing regulations

Photovoltaic panels must comply with a series of guarantees, regulations and be certified. This ensures that the modules are able to withstand the different environmental conditions to which they are exposed during their lifetime (IEC61730, IEC 61215, IEC 61646 or IEC61701).

Perform durability tests according to the specifications of IEC 61215, IEC 61646. The climatic tests to be performed are:

UV preconditioning with a bandwidth of 280 to 385 nm; with a maximum irradiation intensity of 250W / m²; at a module temperature of +60 to ± 5 ° C; and total UV irradiation of 15kWh / m² and a minimum of 5kWh / m² in the bandwidth between 280 and 320nm. This test is intended to precondition the module with ultraviolet light, prior to thermal cycling.

1.8.4 Thermal shock test

50 or 200 thermal cycles from -40 ° C to + 85 ° C.

Purpose

The purpose of this test is to determine the ability of the module to resist thermal imbalance, fatigue and other stresses caused by repeated temperature changes.

Apparatus:

- A climatic chamber with automatic temperature control, means to circulate air within, and means to minimize condensation on the module during the test, capable of thermally cycling one or more modules.

- Equipment for mounting or supporting the module(s) in the chamber to allow free circulation of the surrounding air. The thermal conduction of the support or stand should be low, so that, for practical purposes, the module(s) is thermally insulated.

- Equipment to measure and record the temperature of the module(s) with an accuracy of ± 1 ° C. Temperature sensors should be placed on the front or rear surface of the module near the center. If more than one module is tested at the same time, it will be sufficient to monitor the temperature of a representative sample.

- Equipment to apply a current equal to the maximum power current of the module(s) under test.

- Equipment to control the current flow through each module during the test.

Process:

- Install the module(s) at room temperature in the chamber Fig. 7.7.

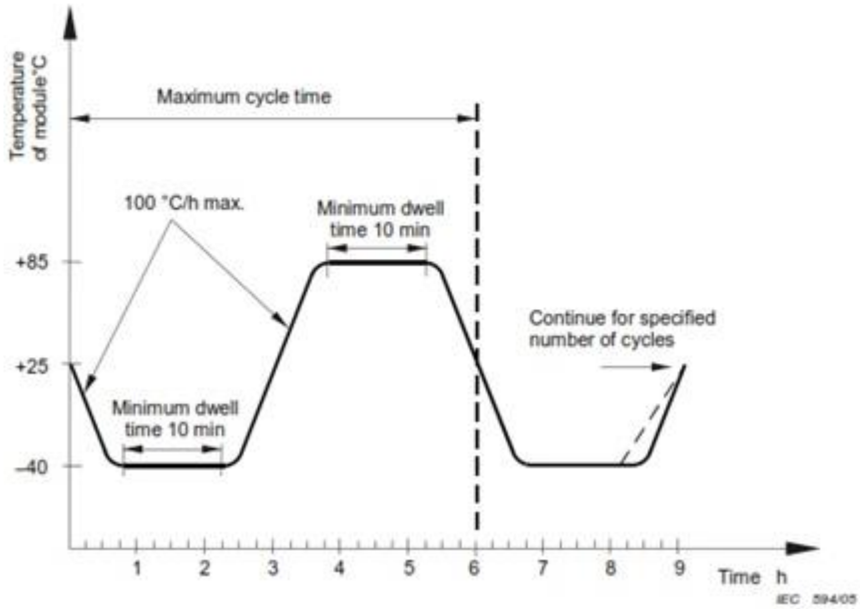
- Connect the temperature monitoring equipment to the temperature sensors. Connect each module to the appropriate power supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly.

During the 200 thermal cycle test, set the current flow to the maximum measured power of the current STC within ± 2%. The current flow shall be maintained only when the module temperature is above 25°C. No current flow is required during the thermal cycle 50 test.

- Close the chamber and cycle the module(s) between module temperatures of -40°C ± 2°C and 85°C ± 2°C, according to the profile in Figure 1.8. The rate of temperature change between the high and low ends shall not exceed 100°C/h and the module temperature shall remain stable at each end for a period of at least 10 minutes. The cycle time shall not exceed 6 hours unless the module is hot, a capability requiring a longer cycle.

- During the test, record the module temperature and monitor the current flow through the modules.

Figure 1.8 Temperature Profile for Thermal Shock Testing



NOTE: In a module with parallel circuits, an open circuit in one branch will cause a discontinuity in the voltage, but will not cause it to go to zero

Source of reference: IEC 61215

Final measurements.

After a minimum recovery time of 1 h, measure the panel power.

Requirements.

The requirements are as follows:

- No interruption of current flow during the test.
- No evidence of visual defects as defined in clause 7.
- Maximum output power degradation shall not exceed 5% of the value measured before the test.
- The insulation resistance shall meet the same requirements as for the initial measurements.

1.8.5 Freezing Test Humidity: 10 cycles from -40°C to + 85°C with 85% relative humidity.

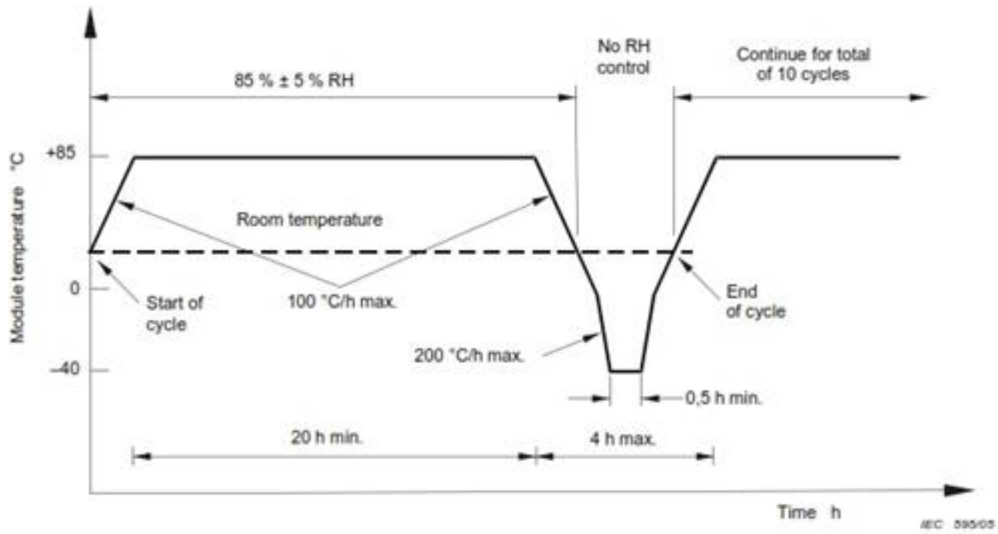
Objective

The purpose of this test is to determine the ability of the module to withstand the effects of high temperatures and humidity followed by freezing temperatures. It should be mentioned that this is not a thermal shock test.

Apparatus

- A climatic chamber with automatic temperature and humidity control, capable of subjecting one or more modules to the freezing cycle specified in Figure 1.9.

Figure 1.9 Humidity-freezing cycle



Reference source: IEC 61215

- Equipment for mounting or supporting the module(s) in the chamber, in order to allow free circulation of the surrounding air. The thermal conduction of the support or stand should be low, so that, for practical purposes, the module(s) is (are) thermally insulated.

- Equipment for measuring and recording the module temperature to an accuracy of ± 1°C. (It is sufficient to monitor the temperature of a representative sample, if more than one module is being tested).

- Equipment for monitoring, throughout the test, the continuity of the internal circuit of each module.

Process

- Place a suitable temperature sensor on the front or rear surface of the modules.

- Install the module(s) at room temperature in the climatic chamber.

- Connect the temperature monitoring equipment to the temperature sensors.

- After closing the chamber, run the module(s) 10 complete cycles according to the profile in Figure 1.9. The maximum and minimum temperature shall be ± 2°C, specified levels and relative humidity shall be maintained within ± 5% of the specified value at all temperatures above ambient temperature.

- During the test, record the module temperature.

Final measurements:

After a recovery time of between 2 hy 4 h, repeat the power and insulation resistance measurement test.

Requirements

The requirements are as follows:

- No evidence of visual defects as defined in clause 7.

- The degradation of the maximum output power shall not exceed 5% of the value measured before the test.

- The insulation resistance shall meet the same requirements as for the initial measurements.

1.8.6 Damp Heat Test: 1000h at + 85 ° C and 85% relative humidity

Thermal and climatic chambers have been developed for large specimens. The test chambers are available in 5 standard sizes (8, 12, 16, 21 and 28 m^2). The unit consists of a fan, a cooling unit, humidification and heating equipment, an on/off system and a control system.

This test is intended to determine the module's ability to withstand the effects of long-term moisture penetration.

Process

The test was conducted in accordance with IEC 60068-2-78 with the following provisions:

a) Preconditioning.

- The modules are introduced into the chamber without preconditioning.

b) Test conditions:

- Test temperature: 85 ° C ± 2 ° C.
- Relative humidity: 85% ± 5%.
- Test duration: 1000 h.

1.9 Results

The importance of verifying and controlling the protection material in solar panels is of vital importance to ensure their useful life. As we all know, Quality Assurance is a system that focuses on products, from their design to the moment they are shipped to the customer and concentrates its efforts on defining processes and activities that allow to obtain products according to specifications.

The average results obtained for gel content (Section 1.8.1) were 82.5 to 87.5%, which indicates that the material will behave correctly during its useful life, ensuring that the modules will not degrade before 25 years. See Table 1.1.

Table 1.1 EVA gel content results

No. of Panel	Gel content in % Gel content in %	Mean	Laminating temperature (°C)	Laminating time (Minutes)
1	85, 90,91,83,82	86.2	145	16
2	79,80,90,92,91	86.5	146	16
3	80,82,79,82,90	82.5	146	15.30
4	90,84,85,87,91	87.5	147	16
5	78,82,84,86,85	83	146	15.30

Source of consultation: Own elaboration

Regarding the adhesion test (Section 2.2), the results obtained are within specification, higher than the minimum established value (25N / cm). Table 1.2, which ensures a good and permanent connection.

Table 1.2 Adhesion test results. After lamination at 150 °C

Sample	Values in 4 areas of the sample in N/cm	Average values in N/cm
1	40, 50, 50, 55	48.8
2	56, 55, 45, 55	52.8
3	56,55,50,56	54.3
4	45,47,50,53	48.8
5	46,48,50,51	48.8

Source: Own elaboration

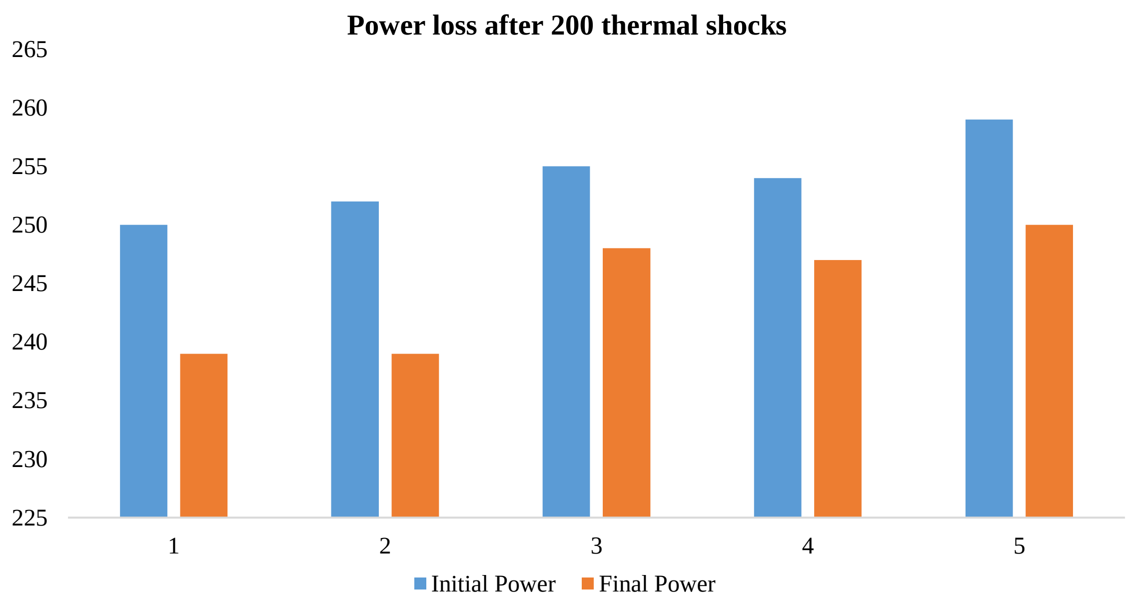
In the ultraviolet (UV) preconditioning test (Section 1.8.4), the EVA did not show any color change. Regarding the 200 thermal cycling tests (Section 1.8.5), it was found that after the test, the power change in 80% of the solar panels is within specification, only one of them showed power slightly above 5%, which is good, and indicates that the EVA served its purpose well, since no discoloration was observed in the material after the test. Table 1.3.

Table 1.3 Power output of solar panels after exposure to 200 thermal shocks

Initial power in Watt	Power after 200 thermal shocks in Watt	Power loss in %. Specification: 5% maximum
250	239	4.4
252	239	5.1
255	248	2.7
254	247	2.8
259	250	3.5

Source: Own elaboration

Graphic 1.1 Power of solar panels after being subjected to 200 thermal shocks



Source: Own elaboration

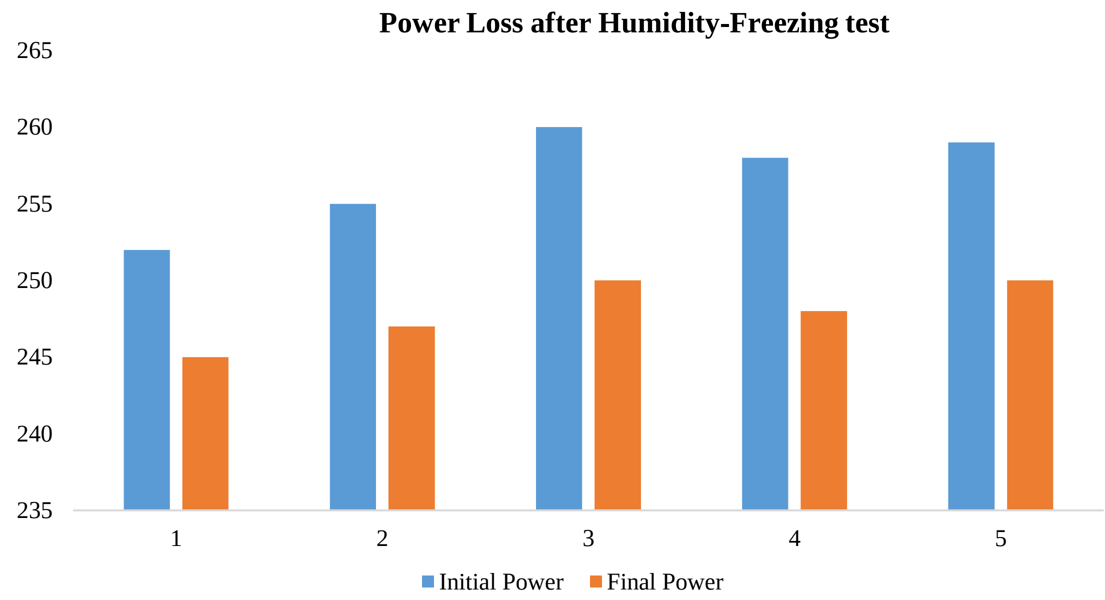
Regarding the freezing humidity test, discussed in section 1.8.5 the solar panels held up, as the power change was 2.8 to 3.9% after the test. Table 1.4, which indicates the good performance of the EVA protection material, as it also showed no colour change.

Table 1.4 Power of solar panels before and after the freezing humidity test

Initial power	Power after 200 thermal cycles	% Power loss Specification 5% maximum
252	245	2.8
255	247	3.1
260	250	3.8
258	248	3.9
259	250	3.5

Source: Own elaboration

Graphic 1.2 Power results after the Humidity-Freezing test



Source: Own elaboration

After the heat-humidity test. Section 1.8.6, no defects were found in the modules, as well as no color change in the EVA protective material.

1.10 Acknowledgements

- To the Centro de Cooperación Academia Industria (CCAI), for its support in the preparation of this chapter.

- To all the collaborators for their dedication and commitment to the realization of this chapter.

1.11 Conclusions

In this chapter, topics of interest for the quality assurance of the encapsulating material of solar panels were addressed, which gives us an idea of the importance of using Metrology in any section of the process for its control. The measurement allows us to know if the characteristics that we want to control in any process are within or out of specification according to the established standards, so that helps us to take preventive actions and continuous improvement in the processes.

With the gel content test, it was found that the lamination process was correct since the gel content values were found to be 82.5% to 87.5% above the specified 80%.

In the adhesion test it was possible to corroborate that the force necessary to peel off the material was within the specification of 50 N / cm to 56N / cm, values above the minimum established in the Standard 40N / cm.

The UV preconditioning test allowed us to confirm that after the test the EVA did not show any colour change, indicating that it did not degrade.

In relation to the durability tests of the solar panels, this study gives us the guideline to ensure the correct operation of the solar panels for at least 25 years, since the measurement of the power loss at the end of the tests allows us to ensure it.

According to the results of the thermal cycles, the number of thermal cycles determines the useful life of a solar panel, the 200 thermal cycles correspond to 25 years of power generation from a solar panel in optimal conditions, if up to this cycle the panel does not decrease by 5% in terms of power loss, so it is assured that it has a longer life than those that degrade before meeting the recommended number of cycles.

In addition, the material after testing showed no significant visible damage (fractures, cracks, bent or deformed surfaces, as well as ground faults).

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