THE IMPACT OF ENGINEERING PLASTICS ON THE ADVANCEMENT OF SOLAR ENERGY IN THE UNITED STATES

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Abstract

The United States photovoltaic (PV) demand has experienced exponential growth in the residential, commercial and utility segments during the past several years and this growth is expected to continue. The growth of this market is due to the drastic reduction in the cost ($/watt) of solar energy systems initiated through the Department of Energy (DOE) Sunshot program which aims to reduce the cost by over 70% by the year 2020.[1] In order to achieve this aggressive goal, alternative materials such as engineering plastics are being considered more than ever before. This paper discusses the impact of engineering plastics on reducing the overall cost while increasing the performance of solar installations in the United States. This paper focuses primarily on the commercial flat rooftop segment of solar due to this segment's traditionally strong growth and high potential for metal to plastic product conversion.

Introduction

The SunShot Initiative goal is to reduce the total installed cost of solar energy systems. This paper focuses primarily on the mounting structures for solar photovoltaic (PV) modules in the commercial flat rooftop market segment. Cost target for these mounting is $0.06 per watt by the year 2020. SunShot program has been very successful up to this point in reducing overall cost of the solar installations by already achieving 60% of the program's target in only three years into the ten year deadline.[1] The average price per kWh of a utility-scale photovoltaic (PV) project has dropped from about $0.21 at the time of Sunshot program launch to $0.11 at the time of writing this paper.[1] Data from the DOE shows continuing solar cost reductions every quarter over the past nine quarters. However, up to this point, the main cost reduction has been in the solar modules themselves. In order to further achieve cost reductions and meet the 2020 target, the focus has moved to 'soft cost' which includes installation.[2] In the arena of reducing installation cost, there are vast and diverse opportunities where engineering thermoplastics such as polyamides and polybutylene terephthalate (PBT) thermoplastic polyester can provide innovative solutions. In addition to reducing installation costs, engineering plastics are being considered to improve performance over traditional incumbent materials such as metals.

In order for companies in the solar industry to remain competitive, they must achieve the cost reduction curve of the Sunshot Initiative. As a result, solar companies that have traditionally only used metals in their products are now reaching out to understand how alternative materials such as thermoplastics can improve their products. BASF Performance Materials has recently been successful in penetrating the North American solar market with engineering plastics at many of these companies. During the past couple of years, the BASF solar team consisting of Commercial and Technical Development has established relationships with over twenty solar companies with presence in four key segments of the United States solar market. These segments include industrial and commercial rooftops, utility scale PV power plants, residential roofing and concentrated thermal solar power (CSP) plants which utilize a large number of mirrors to reflect and focus sunlight to generate heat to produce electricity. Customers in all four segments have either completed commercialization of their applications or are in the prototype phase of development using BASF engineering plastics. The customers span from some of the largest established U.S. based solar organizations to small emerging DOE funded startups. BASF engineering plastics used in these applications have been able to reduce the overall cost of solar installation ($/watt) while improving performance.

This paper will present in detail the advantages, performance requirements and challenges of using thermoplastics in one of the primary strong growth segments of solar, the commercial flat rooftop segment. In addition, some of the BASF engineering thermoplastic materials being applied to the solar applications will be noted.

Advantages, Requirements and Additional Challenges

Advantages of Plastics

There are several advantages to using thermoplastics in all of the four main segments of the solar market. In particular, for the commercial flat rooftop segment, these advantages are very apparent and are being recognized by the solar companies that specialize in PV mounting systems. As of today, the commercial rooftop PV mounting systems are primarily fabricated with structural grades of aluminum alloys or steel. However, as the solar industry learns about the advantages of plastics over the existing metal in current mounting system designs, there is a pendulum shift towards the use of plastics over metals. These key advantages of using plastic over metal materials in PV mounting systems include: (1) Flexibility of being able to design more complex shapes, (2) reducing assembly part count through part integration, (3) lighter weight, (4) inherent material properties such as corrosion resistance, chemical resistance and electrical insulating characteristics, and (5) ease of manufacturability.

The metallic PV mounting systems that are a majority of the commercial rooftop market today are limited to being fabricated by extrusion or stamping. These types of manufacturing methods are very limited in the profile and geometry that can be produced. On the other hand, plastic produced by injection molding allow for highly complex shapes to be created over metals. This in turn provides greater opportunity to take a more creative design approach to the PV mounting systems in developing higher performing mounts at a reduced part cost.

The limited profiles and geometries that are produced with metals lead to multiple part assembly designs. Several parts comprise the metal mounting systems which are commonly attached with up to one dozen fasteners per PV mount depending on the specific design. The multiple pieces of the mount assembly are shipped to the commercial roof solar installation site unassembled. This is done to allow the parts to be more compacted for improved truck trailer fill ratio efficiency in order to reduce the cost of freight and logistics. However, this is one of the key disadvantages to a metal mount design. With the metal design an ultimatum is apparent; the mounts can be shipped preassembled to the installation site sacrificing cost effective shipping or the mounts can be assembled on the rooftop with increased installation labor cost. However, with a plastic design this ultimatum does not exist. The plastic mount can be a one piece design due to the capability of producing complex shapes with injection molding. The multiple parts of the metal design can be redesigned and integrated into one part with plastics. The plastic mount can be designed in such a way to have improved shipping by allowing the mounts to be stackable upon one another leading to shipping fill ratio efficiencies of over 90%. In addition, the one piece plastic design eliminates the extensive use of fasteners which significantly reduces PV installation labor cost. With one of the greatest expenses in the implementation of PV solar on commercial rooftops being labor cost[3], plastic mounts greatly reduce the overall cost in this market segment of solar.

It is well known that fiber filled thermoplastics have a greater strength to weight ratio over most metals. For the solar commercial rooftop industry the lighter plastic material allows for reduced shipping and labor installation expenses. Due to the reduced weight, a greater amount of mounts can be placed on one shipping pallet and once at the installation site be moved up and around the roof with greater ease, once again leading to lower costs.

Plastics have inherent material properties that are idea for commercial rooftop solar mounts. Unlike metals, plastics are corrosion resistant which allow plastic mounts to endure and maintain long term performance in coastal marine environments. Considering that four of the top five US states that lead in quantity of solar PV system installed are coastal states, having resistance to corrosion is a highly desirable design attribute. In addition to corrosion resistance, plastics are chemically compatible with the commercial rooftop membrane. The metal designed mounts require an elastomer pad to be placed between the metal mount and the rooftop membrane to protect between the two materials.[4] A plastic mount can avoid such an elastomer pad which reduces the overall cost of the mounting system. Having a mount produced from an electrical insulating material such as plastic is ideal for frameless glass on glass PV modules. Moving from metal framed PV modules to frameless glass on glass PV modules is the trending direction of the solar industry in order to further reduce system costs and increase mechanical integrity of the module.[5] A plastic mount used in conjunction with a frameless module requires no electrical grounding because there is no metal frame on the module and the plastic mount is a natural electrical insulator. The removal of grounding saves cost in the wiring itself and the labor cost associated with installing it.

The ease of manufacturing of plastics is another advantage. With injection molding, extrusion and low pressure processes, plastics offer a greater selection of fabrication methods over metal materials. With plastics, color is part of the molded piece and no secondary painting operations are necessary to form the aesthetically pleasing black color that many solar customers prefer. Co-injection and insert molding capabilities are other additional options with injection molding.

Overall, there are several substantial advantages with applying plastics to the commercial flat rooftop market over their metal counterparts in reducing the cost of solar while enhancing the PV system performance.

Performance Requirements

Despite there being clear advantages to applying plastics to the commercial flat rooftop PV mounts; there are several performance requirements and challenges that need consideration. Basic requirements are defined by specifications written by independent safety science organizations such as Underwriter Laboratories (UL). In addition to the UL specifications there are customer driven requirements and engineering design challenges. In general, PV mounts are subjected to sometimes very challenging climates such as high ultraviolet radiation, extreme fluctuating cold and hot temperature, humidity, snow loading and high winds from hurricanes. The PV mount is required to maintain its mechanical performance over 20-30 years under these environmental conditions. In addition to environmental requirements, resistance to flame spread and ignition is critical for a rooftop solar application.

Well defined standards are being implemented to ensure the materials in solar applications are able to meet the performance requirements. The most notable standard for commercial flat rooftop PV mounting applications is Underwriter Laboratories (UL) standard 2703 ‘Mounting Systems, Mounting Devices, Clamping/retention Devices and Ground Lugs, for use with Flat-Plate Photovoltaic Modules and Panels’. This standard references several other UL standards to define key performance requirements for commercial flat rooftop solar installations where a polymeric material is used in a rack mounting system and/or clamping device. The UL standards applied to polymeric materials include:

• UL1703 ‘Standard for Flat-Plate Photovoltaic Modules and Panels’ which is a comprehensive standard that focuses on requirements pertaining to the PV modules.

• UL 746C Ultraviolet Light Exposure which states after 1000 hours of Xenon arc test or equivalent, the average physical property values after UV conditioning shall not be less than 70 percent of original values.

• UL 746C Water Exposure and Immersion which states the average physical-property values after the water exposure and immersion conditioning where the material is immersed in distilled or deionized water at 70 ±2°C (158±4°F) for 7 days shall not be less than 50 percent of the original values.

•UL 2703 Minimum Relative Temperature Index (RTI) Mechanical without Impact value of 95°C described by Polymeric Materials – Long Term Property Evaluations, UL 746B. To meet this requirement the average mechanical property values of the material after long term thermal aging at 95°C shall not be less than 50 percent of original values.

A photovoltaic mounting system, regardless of the material, that is intended to be installed on a roof shall be evaluated for fire performance in accordance with UL 1703 Section 16. The flammability requirement is a system level test consisting of the PV module and mounting assembly. System fire class ratings A, B, or C are defined by the spread of flame at roof and module or panel interface over a representative low sloped roof; Class A having a flame spread of less than 6 feet in 10 minutes, Class B less than 8 feet in 10 minutes and Class C less than 13 feet in 4 minutes. Since this is a system level test it is not possible to predict the performance solely on type of material from which the mount is fabricated. The flame performance is highly dependent on the geometric design of the mount and how it attaches to the solar module. Features such as north, east and west wind deflectors attached to the mount/module system aid in preventing the flame spreading under the module. This control of the flame spread from under the module is one of the keys to passing the flammability requirement.

Additional Challenges

In addition to the UL standards and customer requirements, there are other engineering design considerations when applying thermoplastics to solar applications. One consideration is creep. Creep testing consists of measuring the extension or compression as a function of time and time to rupture, or failure of a specimen subject to constant tensile or compressive load under specified environmental conditions. It is necessary to predict the creep behavior to predict the dimensional changes and failure that may occur as a result of time dependent loads. In some regions of the U.S., the solar mounting systems experience significant snow loads for several consecutive months. Solar mountings are often required to meet the same snow loading as the commercial rooftop in which they sit. In some states and municipalities the snow requirement is as high as 55lbs/sq. ft. which represents two feet of wet dense snow.[6] In addition to snow loads, many solar companies require mechanical integrity with wind loads of up to 120MPH which is equivalent to a Category 3 hurricane. With this high wind load requirement, cyclic fatigue and static creep need to be considered in the mount’s design. Another customer requirement for the mounting system is to withstand short term vibrational fatigue from seismic activity.

It is interesting that UL2703 requires only 1,000 hours of ultraviolet (UV) radiation material validation testing which represents approximately a two year exposure timeframe. Due to customers offering up to 25 year warranties on PV mounts, additional long term testing should be considered such as artificial accelerated weathering which involves a laboratory UV radiation source, thermal stress, and moisture (in the form of relative humidity, and/or water spray, condensation, or immersion) in an attempt to more rapidly produce the same changes that occur in long term outdoor exposure. Real life exposure testing is impractical because of the timeframe to produce actual results. However, artificial accelerated weathering should consider standardized conditions to simulate Florida climate conditions of high humidity environment and/or Arizona climate to test the suitability against very high UV radiation.

Discussion

BASF Performance Materials has offered broadly two categories of engineering plastics in solar commercial rooftop applications. These engineering thermoplastics include both Ultramid® (PA: polyamides) and Ultradur® (PBT: polybutylene terephthalate). Plastics performance is enhanced with fibers, UV stabilizers, flame retardants, hydrolysis resistant and other types of additives to be tailored to specific customer requirements.

Figure 1, shows the specific UV performance of a BASF Ultramid® glass fiber reinforced polyamide.[7] This data is from an actual outdoor automotive component that has been exposed to the outside environment for fourteen years. The graph shows that 77% of the tensile strength of the material has been maintained.

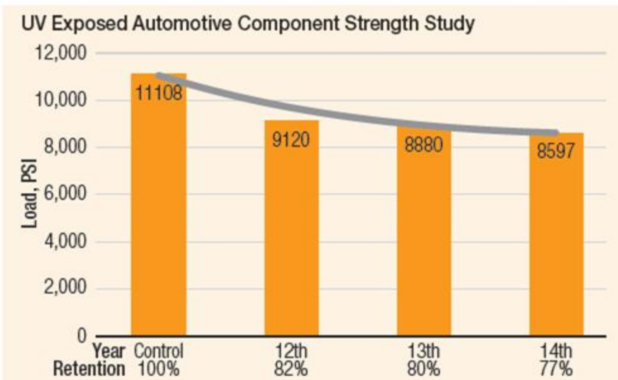

Figure.1: Tensile strength retention over years of service. Actual UV exposed glass fiber reinforced Ultramid® automotive component.

Figure 2 and Figure 3 show Xenon arc accelerated weathering results approximating greater than 20 years of UV exposure under Florida conditions for a BASF Ultradur® glass fiber reinforced polyester blend. The graph shows that 98% of the tensile strength of the material has been maintained as well as high retention in tensile modulus. Both of these graphs show how polyamides and polyesters are highly effective in meeting one of the most demanding solar material requirements. The graphs show long term UV data availability in both actual and artificial testing scenarios. Although the large majority of the mechanical properties are maintained under long term UV exposure it is important to note that there is typically some minor surface degradation in engineering plastics from UV which causes the black colored material to gray. This gray layer affects the aesthetics of the material but becomes a protective layer against further UV attack.

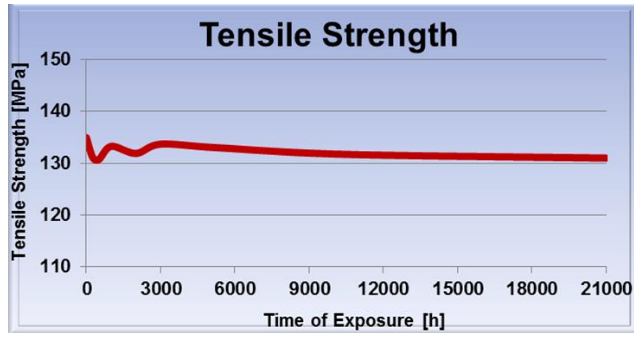

Figure 2: Tensile strength retention under accelerated Xenon-arc UV weathering of glass fiber reinforced Ultradur®

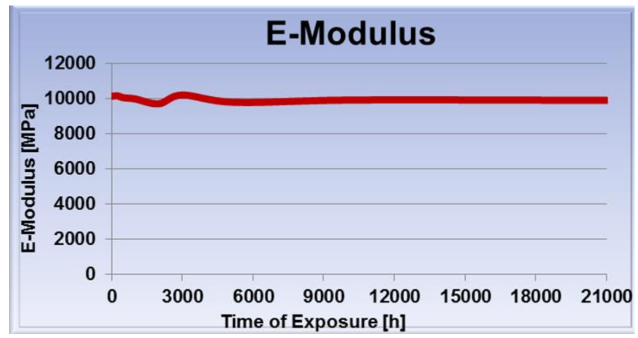

Figure 3: Tensile modulus property retention under accelerated Xenon-arc UV weathering of glass fiber reinforced Ultradur®

Figure 4 and 5 show additional performance characteristics of Ultramid®. Figure 4 shows creep behavior of a PA6 reinforced with 33% short glass fiber. Although creep needs to be considered early in the application development process when calculating the safety factor required from the design, creep behavior is not significant enough to limit the usage of the material in solar structural mounts. Figure 5 shows the dependency of tensile strength on temperature and moisture retention percentage of a PA6 reinforced with 33% short glass fiber.[8] There is a significant reduction in tensile strength from both elevated temperature and high moisture retention percentage which are independent phenomena. This is an important characteristic of the PA6 material to account for in the application design. When designing solar structural mounts it is best practice to design with the worst case environmental conditions as a starting point and add a safety factor from there. In the North American solar market these dependencies become highly evident under Florida conditions where the commercial rooftop has the potential to experience average annual relative humidity of 80% at temperatures up to 90°C.

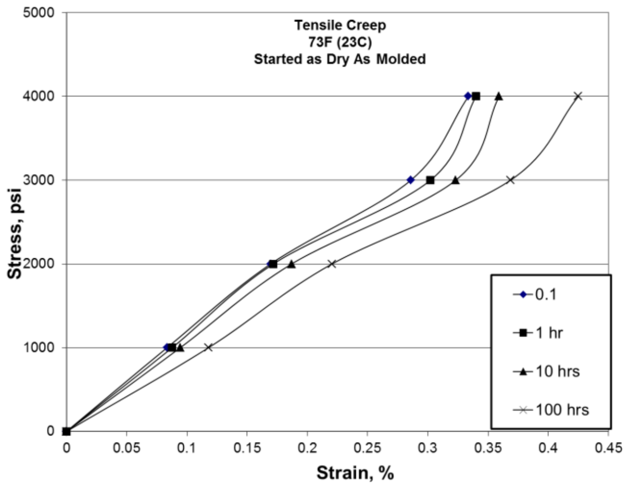

Figure.4: Creep behavior for glass fiber reinforced Ultramid® with 33% short glass fiber.

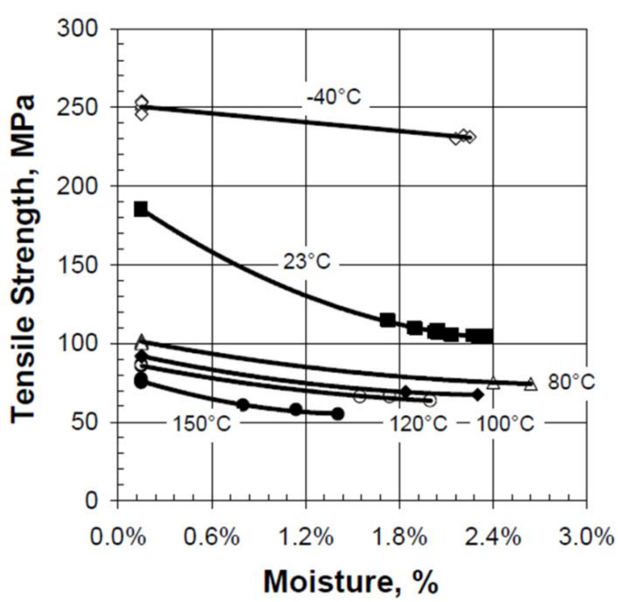

Figure.5: Tensile strength retention verse temperature and moisture uptake % for Ultramid® with 33% glass fiber content.

Conclusion

Thermoplastics offer several advantages in solar applications and in particular commercial flat rooftop structural PV mounts. These advantages are being recognized by solar companies and there is a high level of interest in using plastics to replace the incumbent metallic materials. As installation of frameless glass on glass PV modules continue an upward growth trend, mounts produced with plastic will follow the same trend. Additional material testing to show long term plastic outdoor performance to gain customer confidence will aid in the growth of plastics in the solar market. Overall, plastics have a bright future within the solar industry.

Acknowledgements

The authors gratefully acknowledge the support provided by the following BASF Performance Materials colleagues; Hung Pham, Alternative Energy Market Manager and Marios Lambi, Application Development and CAE Manager for their support and commitment to solar related projects. Andre Schaefer, Alternative Energy Business Manager BASF Europe, for the Ultradur® testing data presented in this paper.

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