Durable Concentrating Solar Power (CSP) Mirrors

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Abstract

To convert sunlight into electricity, an array of concentrating solar power (CSP) mirrors is arranged to reflect and focus the sun light onto a receiver containing a heat absorbing fluid. The hot fluid is then used to generate electric power through heat transfer mechanisms and standard steam turbine. There have been constant efforts to increase the solar reflectivity of the mirrors and to improve the durability of the mirror backing paint for the severe environment of the solar fields. The Guardian CSP mirrors successfully improved these performance metrics by laminating a polyvinyl butyral (PVB) film behind the mirror coating with a backing glass to seal the assembly. The design allows the use of 1.6 mm thin glass for the mirror which significantly increases solar reflectivity. In addition, with PVB lamination, the mirrors do not shatter when damaged by strong winds or stones. This not only prevents subsequent damage to other mirrors and the tube glass vacuum jackets, but also the CSP mirrors can continue to reflect sunlight, reducing the repair frequency. When compared to organic type paints, the backing glass has less vapor permeability hence provides the best protection to the mirror metals. High lead content paint systems have historically exhibited good long term durability performance. EcoGuard laminated reflectors seal the mirror coatings directly between two pieces of glass eliminating the need for any protective paints and thus offering benchmark durability while being completely free of lead. Environmental testing has proven that this design of solar mirror is durable and retains its high reflectivity of over 94.5% for a long period of time.

Introduction

Solar energy is one way to reduce greenhouse gas emissions and fuel consumption. The sun’s energy can be converted into other forms of energy mainly through photovoltaic cells and thermal exchange systems. For the thermal exchange systems, the power generation works essentially the same as generation from fossil fuels except that instead of using steam produced from the combustion of fossil fuels, the steam is produced by the heat collected from sunlight. It uses hundreds to thousands of sun-tracking mirrors to reflect and concentrate the sun’s energy onto a receiver to increase the conversion.

Currently, the glass based concentrating solar power (CSP) mirrors can be grouped into two types: single layer monolithic mirrors and multilayer laminated mirrors. For the monolithic mirrors, as depicted in Figure 1, they can be flat or heat bent before silvering and the backing paint is the protective layer for silver and/or copper metals against the environment. For laminated mirrors, as depicted in Figure 2, the front glass can be flat, cold bent or heat bent. The backing plate is then laminated to the silvered front plate as the protective layer against the environment. The laminated designs are aimed at better reflectivity and better durability.
The purpose of this paper is to introduce a new construction of these sun-tracking mirrors with superior reflectivity and durability.

**Manufacturing Process**

In this design the mirror is made with a thin front glass and a thicker backing glass laminated with polyvinyl butyral (PVB) film in between as illustrated in Figure 3. For curved mirrors a thin solar glass and a thicker backing glass are bent together to the required curvature at elevated temperatures. After cooling down, the resulting glass plates will maintain shape without the need of extra boundary conditions. The thin glass is then separated from the backing glass and coated with silver and copper layers for the required reflectivity. Lastly, the reflective front glass and the backing glass are laminated with PVB, through an autoclave process for optimum adhesion and edge seal. In the case of flat laminated mirrors the bending process step is omitted.

**Testing Results**

The new flat or curved mirror design with PVB is a proven technology that has been used for the past 60 years in automotive and architectural applications. An earlier version of laminated reflector panels made by Guardian have been in service over 30 years at Sandia National Labs Central Receiver Facility. While some have been broken due to impacts over the years,
the entire set remain functional with only mild corrosion at the edges. Cracked parts are still fully intact and functional without apparent corrosion at the cracks. In contrast, for any monolithic design, cracked parts would be broken in pieces and immediately rendered useless as reflectors. This new design of mirror is much more durable when compared to other mirror designs during accelerated testing as shown below.

• **Copper Accelerated Acetic Acid Salt Spray (CASS) Test**
  The mirrors passed 3500 hours of CASS test without any corrosion. The backing glass of this design is hermetic. There is no possibility for developing corrosion spots through the backing glass. The edges of the silver and copper metal layers are deleted in the design, enabling the PVB to adhere directly to the glass at edges forming a good seal without introducing additional sealer of different type materials.

• **Salt Spray (SS) Test**
  The mirrors passed 3500 hours of SS test without any corrosion for the same reason as the above CASS test.

• **Humidity test**
  The mirrors passed 3500 hours of constant humidity test without any corrosion or delamination.

• **Climate Cycling Test**
  The mirrors passed the test between -35°C and +85°C for 120 days. No visible degradations and no measurable change in curvature were found.

• **UV test**
  The mirrors pass 33 years at Sandia National Laboratory solar site without delaminations. Some have remained in service for many years after breakage due to impacts.

• **Damp Heat**
  The mirrors were soaked at 85°C and 85%RH for over 8500 hours without delamination and without reflectivity loss.

• **Wind Tunnel Test**
  The laminated design resists higher wind resistance than the monolithic design as indicated by the comparison shown in Figure 4. The laminating material effectively dampens the natural frequency of the glass resulting in a more stable product under dynamic loading and less vibration induced focus loss under moderate wind conditions.
It should also be noted that the PVB laminated mirrors will continue reflecting and concentrating the sun’s rays even if broken. Figure 5 shows a sample mirror which was broken at installation and left in place for testing. After three years, the mirror is still operational and has no sign of degradation.

- **Outdoor Exposure Test** - Equatorial Mount with Mirrors for Acceleration with Water (EMMAQUA)

This test concentrates natural sunlight via 10 highly reflective, specially coated mirrors onto the specimen target area with an intensity of approximately eight suns. The device tracks the sun and exposes specimens to the full spectrum of sunlight.

The following chart shows the testing result after up to 120 equivalent months (3500 MJ/m²) of UV dosage and 240 months of visible exposure on one set of mirrors and another set with testing still in progress which will continue to 240 months UV and 480 months visible exposure. The loss of solar reflectivity is less than 1% after the 10 year equivalent Arizona UV exposure level.
Conclusions

Compared with monolithic mirrors, the new laminated design allows the use of thinner front glass which greatly increases the reflectivity. This design takes advantage of a technology which has proven outdoor durability. The outdoor durability of the current low lead mirror backing paints used on the monolithic design is yet to be proven. Additionally, the new laminated design does not contain lead and other hazardous materials as required in most mirror backing paints. Also, there is no need to increase the precious metal thickness to block the UV rays from reaching the paint which could lead to paint degradation. Compared with other laminated cold bent design mirrors, the final assembly of the new curved design is stable and has much lower residual stress since the stress is released during cooling after bending. The new mirror design with PVB is much more durable than other designs using mirror backing paints and adhesives. It will continue reflecting and concentrating the sun’s rays even if broken.

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References