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Durability of Polymeric Glazing and Absorber Materials

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ABSTRACT

The Solar Heating and Lighting Program has set the goal of reducing the cost of solar water heating systems by at least 50%. An attractive approach to such large cost reduction is to replace glass and metal parts with less-expensive, lighter-weight, more-integrated polymeric components. The key challenge with polymers is to maintain performance and assure requisite durability for extended lifetimes. The objective of this task is to quantify lifetimes through measurement of the optical and mechanical stability of candidate polymeric glazing and absorber materials. Polycarbonate sheet glazings, as proposed by two industry partners, have been tested for resistance to UV radiation with three complementary methods. Incorporation of a specific 2-mil thick UV-absorbing screening layer results in glazing lifetimes of at least 15 years; improved screens promise even longer lifetimes. Proposed absorber materials were tested for creep and embrittlement under high temperature, and appear adequate for planned ICS absorbers.

1. Objectives

Improved polymeric glazing and absorber materials are required to increase the reliability of cost-effective solar collectors. A review of development efforts involving polymeric solar collector systems is provided in [1]. As discussed in the Solar Program Multi-Year Technical Plan [2], a major impediment to development of low-cost solar water heating systems is the uncertainty in durability of polymeric components. Both passive solar water heating and active cold-climate solar water heating technologies require polymeric glazings and absorbers to survive in harsh operating environments. The objective of this research is to perform materials testing to demonstrate the durability of candidate polymers and allow realistic estimates of their service lifetimes.

2. Technical Approach

The primary property of interest for candidate polymeric glazings is their ability to forestall optical and mechanical degradation (yellowing and embrittlement) caused by exposure to temperature and UV light. A number of candidate glazing constructions have been subjected to photothermal weathering using three complementary forms of exposure. These include outdoors, in accelerated weathering chambers, and at NREL's unique UV-concentrator facility.

To assess the thermal stability of candidate polymeric absorber materials experiencing elevated temperatures associated with glazed collectors, mechanical properties (tensile modulus and strength, and strain at break) were measured as a function of time of thermal exposure to dry air and to heated deionized water. Creep measurements were also made at a variety of temperatures and stresses to address concerns about permanent deformations (large-scale bulging of the absorber materials) occurring during operation.

3. Results and Accomplishments

3.1 Glazings

Various candidate polycarbonate (PC) glazing material constructions have been subjected to accelerated exposure testing at a light intensity level of 50 UV suns for up to an equivalent of 20 years outdoor exposure in Miami, FL (see Fig. 1). The most promising construction uses a UV-screening film that is laminated to a PC sheet with an optically clear adhesive. Without the additional UV-screening layer, PC products (even those that incorporate an integral UV cap) exhibit 3–5% loss in performance (solar-weighted hemispherical transmittance) after about 2–3 years equivalent exposure. In addition, severe visual yellowing (an aesthetic concern) occurs in the same timeframe.

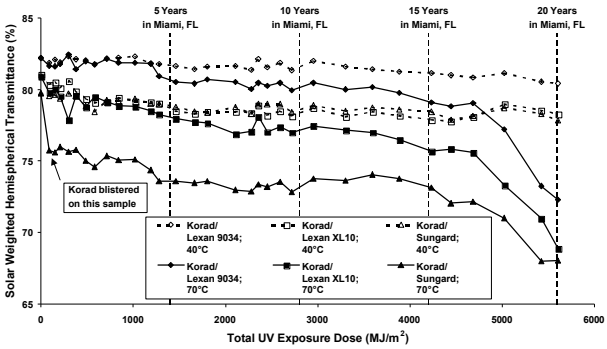

Fig. 1. Solar-weighted transmittance of various polycarbonate samples with Korad shield during UV-concentrator exposure.

With the addition of a UV-screening film (Korad®), significant loss in hemispherical transmittance does not begin for samples exposed at 70 C until after ~15 years equivalent outdoor exposure. Samples exposed at 40 C exhibit greater durability. The loss in transmittance after prolonged weathering is not unexpected, because the UV-screening functionality of the Korad® film degrades with UV exposure. However, a modified UV-screening film (having either increased thickness or increased loading with UV absorbers) could likely be expected to extend the useful

life of PC glazings. We are presently testing several alternate UV-screening films. In addition, UV absorbers having greater photopermanence are being developed by the polymer additives industry and will be evaluated for use with PC glazings. Solar manufacturers have constructed prototype collectors using thermoformed glazings in which the Korad® UV-screening film has been thermally laminated to as-extruded PC sheets. We have found that glazing samples produced this way do not exhibit adequate optical durability during accelerated exposure testing. Further research and testing are required and are being pursued to investigate this result.

3.2 Absorbers

The mechanical properties of two candidate absorber materials, namely metallocene-based multi-density polyethylene (MBMDPE) and polypropylene (PP), were measured as a function of wet and dry thermal exposure. In general, little loss in tensile properties was found for samples exposed wet. However, materials were observed to become stiffer and less ductile after exposure to elevated temperatures in both water and air. The MBMDPE was particularly susceptible to this effect and would often "snap" quite early during tensile testing. Samples of PP prepared from material perpendicular to the machined direction (transverse) exhibited a greater tendency toward stiffness than samples prepared that were parallel to the machine direction (longitudinal). For the length of time tested, both MBMDPE and PP seem suitable as absorber materials as long as dry stagnation conditions can be avoided. This would be the case for materials used in integrated collector storage systems that are never dry until failure occurs. The most noticeable mechanical weathering effect has been significant loss of strain at break (see Fig. 2). As long as a reasonable residual strain at break is retained (i.e., does not reduce to nearly zero), the absorber materials are useable. If exposure conditions are too severe (such as prolonged exposure at elevated dry stagnation temperatures), the absorber materials become very stiff and may no longer perform adequately during service.

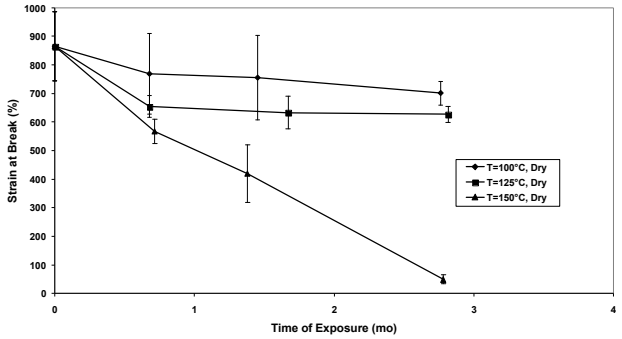

Fig. 2. Strain at break of PP (longitudinal orientation) as function of exposure time at different temperatures in air.

Creep was measured over a representative range of temperatures (30–90 ºC) and stresses (0.52–2.76 MPa). This allows creep compliance (D) to be calculated for a range of temperatures and stresses experienced during operation. The creep compliance master curve at a particular reference temperature and stress can then be obtained by shifting measured values of D(t) to a new (extended) time. The resulting creep compliance master curve (see Fig. 3) suggests that MBMDPE continues to creep with time. Approximately 2% strain will occur in about 10 years (~$3x10^8$s) at the reference stress and temperature condition.

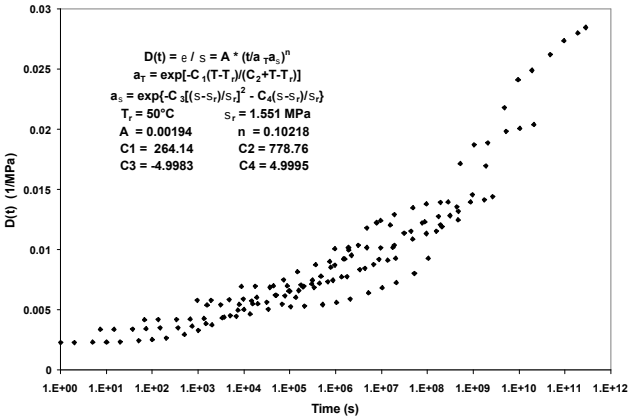

Fig. 3. Creep compliance master curve for MBMDPE.

4. Conclusions

Glazing material constructions in which a UV-screening film is laminated to a PC sheet with an optically clear adhesive have demonstrated optical durability for 15 years equivalent exposure in Miami, FL. It is likely that the service lifetime of such glazings can be extended by using improved UV-screens that are thicker or incorporate UV absorbers having greater photopermanence. Glazing constructions in which the UV-screen is thermally bonded to the PC substrate exhibit yellowing much earlier; the causes of this effect are being investigated.

The mechanical properties of MBMDPE and PP absorber materials were measured as a function of wet and dry thermal exposure. In general, little loss in tensile properties was found for samples exposed wet. However, materials were observed to become stiffer and less ductile after exposure to elevated temperatures in both water and air. For the length of time tested, both PE and PP seem suitable as absorber materials as long as dry stagnation conditions can be avoided.

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[1] J.H. Davidson, S. C. Mantell, and G. J. Jorgensen, "Status of the Development of Polymeric Solar Water Heating Systems," *Advances in Solar Energy, An Annual Review of Research and Development, Vol. 15*, D.Y. Goswami, Ed., American Solar Energy Society, Inc., Boulder, CO, 2003, pp. 149-186.

[2] *Solar Energy Technologies Program Multi-Year Technical Plan, 2003-2007 and Beyond*, DOE/GO-102004-1775, U.S. Department of Energy, Washington DC, January 2004.

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