Artificial Aging Properties of an Extruded Polymeric Solar Collector

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Abstract

A Solar hot water collector, manufactured from polymer materials, has been studied to produce low temperature water with low cost production in order to assist electrical safety, which is more suitable for Thailand's energy usage. The polymer collector used in this study was PVC composite (PVC-C). This material, with a conduction rate of 0.24 W/m K, was investigated through ASHRAE 93- 77 standard procedures and compared with a commercial solar collector made from a polyphenylene ether blend with polystyrene (Noryl). The mechanical properties testing used in this study are tensile strength, modulus, and elongation at break, before and after aging at 50°C for 10,000 hr in order to indicate aging. The lifetime expected from aging results for PVC-C was more than 8 years durability under these experimental testing conditions.

Keywords: Polymeric solar collector, Thermal efficiency, Artificial aging, Mechanical properties

1. Introduction

Solar collectors are widely used overseas, especially in European countries and China. In Thailand, they rarely are used due to price, lack of specialists, and high maintenance cost. To encourage the use of solar collector, fabrication of a low-price solar collector, made from low-price materials, is of interest due to cost saving and a reduced trade deficit from the importing of electric and gas hot water heaters. A copper-made solar collector causes problems as follows:

- The problem of tube expansion due to heat and tube wiggle-caused leakage at joint
- Copper oxide or rust will make water to be green in the case of lack of hot water usage
- Smell from copper oxide
- Copper tubing is easy to cool down. This cause redundant electric usage, especially for long tubes.

The application of thermoplastics is of interest because of less expense, lighter weight, with more integrated materials [1]. In the previous work [2-7], glazed and unglazed polymeric solar collectors have been widely used for heating of swimming pools, space heating, and domestic hot water preparation. However, most previous works pay attention to the glazing materials with high temperature production. For example, fluoro-polymers were proposed to be a good plastic collector because of their excellent thermal and optical durability, but are expensive and are limited to collector designs. Also, polyetherimide (PEI), polyimide (PI), and polycarbonate (PC) were also suggested for consideration. However, those plastic materials are quite expensive. Thus, the challenge is to find plastic materials, which are suitable for low temperature heating in Thailand, which are suitable for collectors and preheater. We are seeking low cost plastics, in a group of olefins, to compare with commercial plastics used for solar collectors.

In this study, artificial aging of polymeric solar collector materials is investigated in order to prevent damage for prepared solar collectors. The lifetime is estimated from the measurement of QUV accelerated weathering.

2. Experimental

2.1 Materials

Materials used in this study were Polyvinyl Chloride Composite (PVC-C) and Polyphenylene ether blended with polystyrene (Noryl EN150 SP), commercial grade which were extruded from pellets to make a panel. The solar collector panel was assembled in 1 m width and 2 m length.

2.2 Experimental

The solar collector is made of composite materials in order to measure the thermal efficiency of solar hot water panels. The collector efficiency evaluation is based on a temperature profile of the water temperature inlet and outlet during the day. The experiment was conducted by exposing the collector panels under direct solar radiation over several days and measuring the water inlet and the outlet temperature according to standard ASHRAE 93-77 [8]. The solar radiation incident on the plane of the collector angle 14^{o} should exceed 790 W/m^2, recorded by Pyranometer, Kipp&Zonen, CMP 3. Temperature inputs, output, and ambient were collected by portable data station Yokogawa Datum-Y, XL100. The flow rate is constant at 0.02 kg/s.

The thermal efficiency of each type of plastics solar collector is measured during the solar exposure, which heats up the water inside the tube. The determination of the temperature change is**:**

$$\Delta T = T_{out} - T_{in} \tag{1}$$

The usable power heats up the water due to the following equation:

$$Q_u = m.C_p\,(T_{out} - T_{in}) \tag{2}$$

Where:
Q_u: the useful energy
m: mass flow rate [kg s]
C_p: specific thermal capacity [KJ/ kg.^{o}C]

$$I_T = (S\ /\ Factor\ of\ pyranometer) \times 1000 \tag{3}$$

I_T: solar radiation in the collector plane [W.m^2]
S: Sunlight

From each set of measurements (i.e. for each inlet temperature), the average efficiency was produced based on the equation:

$$\eta = (Q_u / A_c.I_T) \times 100 \quad (4)$$

Q_u = the useful energy
Ac = the collector area [m^2]
I_T = solar radiation in the collector plane [Wm^2]

The collector's flow rate during measurements was set at 0.02 kg/s.m^2. The ambient temperature, $T_{amb,}$ panel temperature, T_p, water inlet temperature, T_{in}, and water outlet temperatrue, T_{out} , are measured every 1 minute from 9 AM until 4 PM and recorded using a data logger. The sensors used was a K-type thermocouple. The solar radiation energy exposed the collectors to an intensity between 1000-700W/m^2 , and solar radiation was detected by a pyranometer. The experiment was set up as seen in Fig. 1.

2.3 Lifetime Estimation

The dumbbell specimens were placed into an Accelerated Weathering Tester QUV [9], as shown in Fig. 2, and the weathering testing was measured using UVB with 313 nm at 50^{o}C for 10,000 hours, and the data was collected every 500 hours.

2.4 Mechanical Properties

Mechanical properties were measured by a universal testing machine. From the stress-strain curve, we can calculate tensile strength, modulus, and elongation at break.

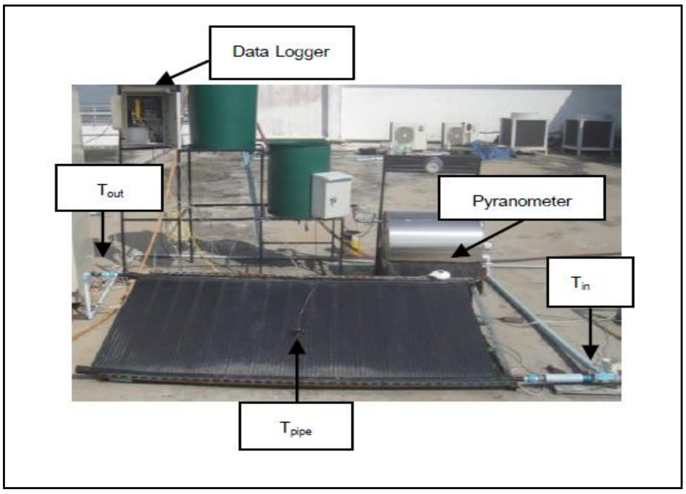


Fig. 1. Experimental set up for thermal efficiency test, following standard ASHRAE 93 -77.

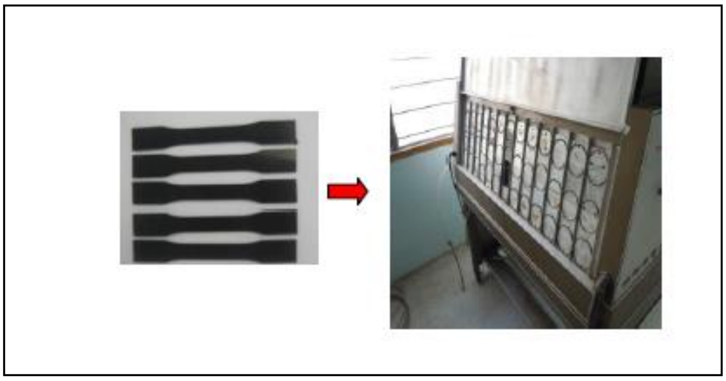


Fig. 2. Dumbell specimens for accelerated weathering testing (QUV).

3. Results and Discussion

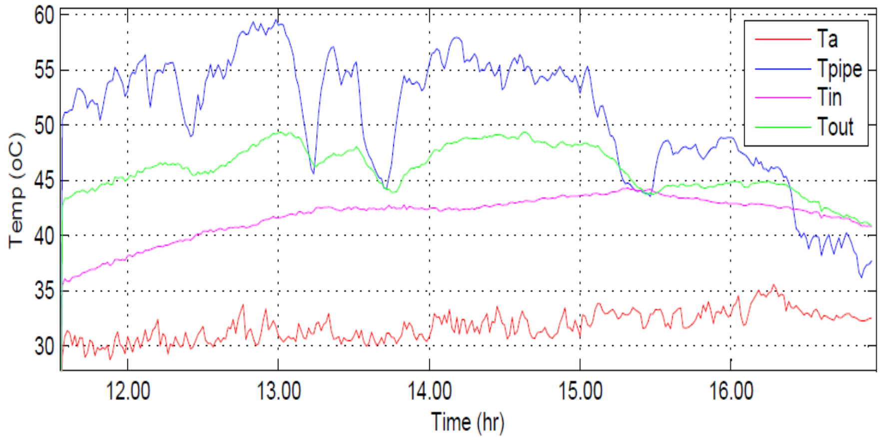
Tensile strength, Young's modulus, and elongation at break for PVC-C and Noryl are shown in Table 1. It was found that the tensile strength and elongation at break for both materials are quite similar. However, the Young's modulus of PVC-C is higher than Noryl by almost double. This may be due to the effect of filler which was incorporated into PVC. The ability of a solar collector to absorb and transfer solar heat into the liquids flowing within the panel is critical to the absorber thermal efficiency. The experment was conducted at Rajamangala University of Technology Thanyaburi, and follows standard ASHRERE 93-77. The time and temperature profiles of the water inlet and outlet for each solar collector panel is analysed using Matlab and shown in Fig. 3.

The calculated thermal efficiency by plotting the x-axis, which is $(T_{in}-T_a)/I_c$, *versus* the y-axis, which is the collector thermal efficiency (%), is shown in Fig. 4. From Fig. 4, the extrapolation to the y-axis is analyzed as the collector thermal efficiency, and the slope of the curve represents the heat loss of each material without glazing. It can be seen that the efficiency of PVC-C (2 m^2 area) and Noryl (1.8 m^2 area) were 50 % and 40 %, respectively.

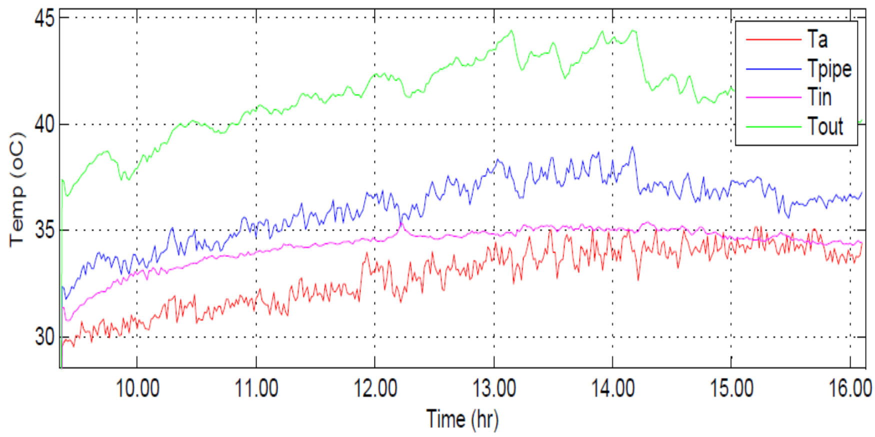
The data of tensile strength, modulus, and elongation at break as a function of aging time are depicted in Fig. 5 for PVC-C and Noryl. There is a rather large scatter in the results of elongation at break. The tensile strength and modulus were found to be similar. Thus, for this material, it is necessary to investigate conditions in water, in air, and with heat to specify aging mechanisms for further investigation.

Table 1. Mechanical properties for PVC-C and Noryl.

Materials	Tensile strength (MPa)	Young's Modulus (MPa)	Elongation at break (%)
PVC-C	42.2	2,643.5	7.7
Noryl	44.1	1,888.6	5.2



(a)



(b)

Fig. 3. Temperature profile for water input.(T_{in}), water out (T_{out}), panel temperature(T_p) and ambient temperature (T_{amb}) for solar collector : (a) PVC-C and (b) Noryl.

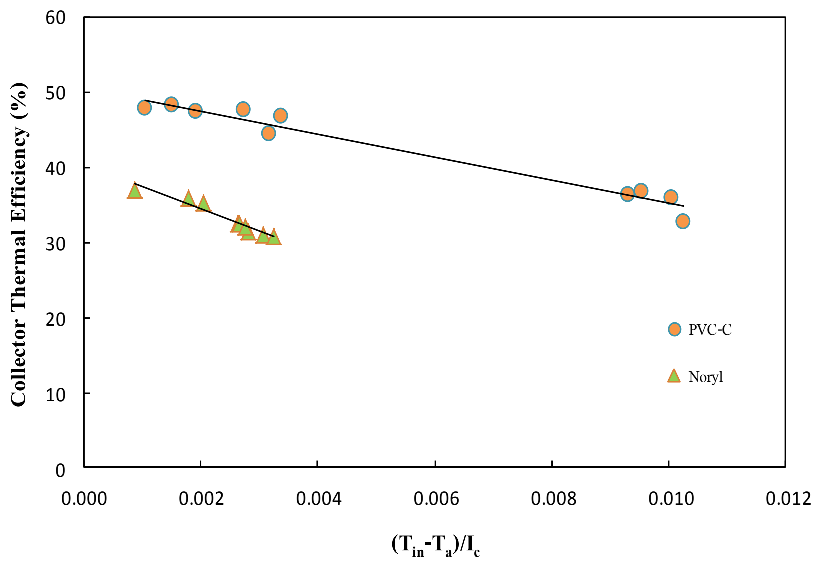


Fig. 4. Collector thermal efficiency for a polymer composite solar collector made from PVC-C and Noryl materials.

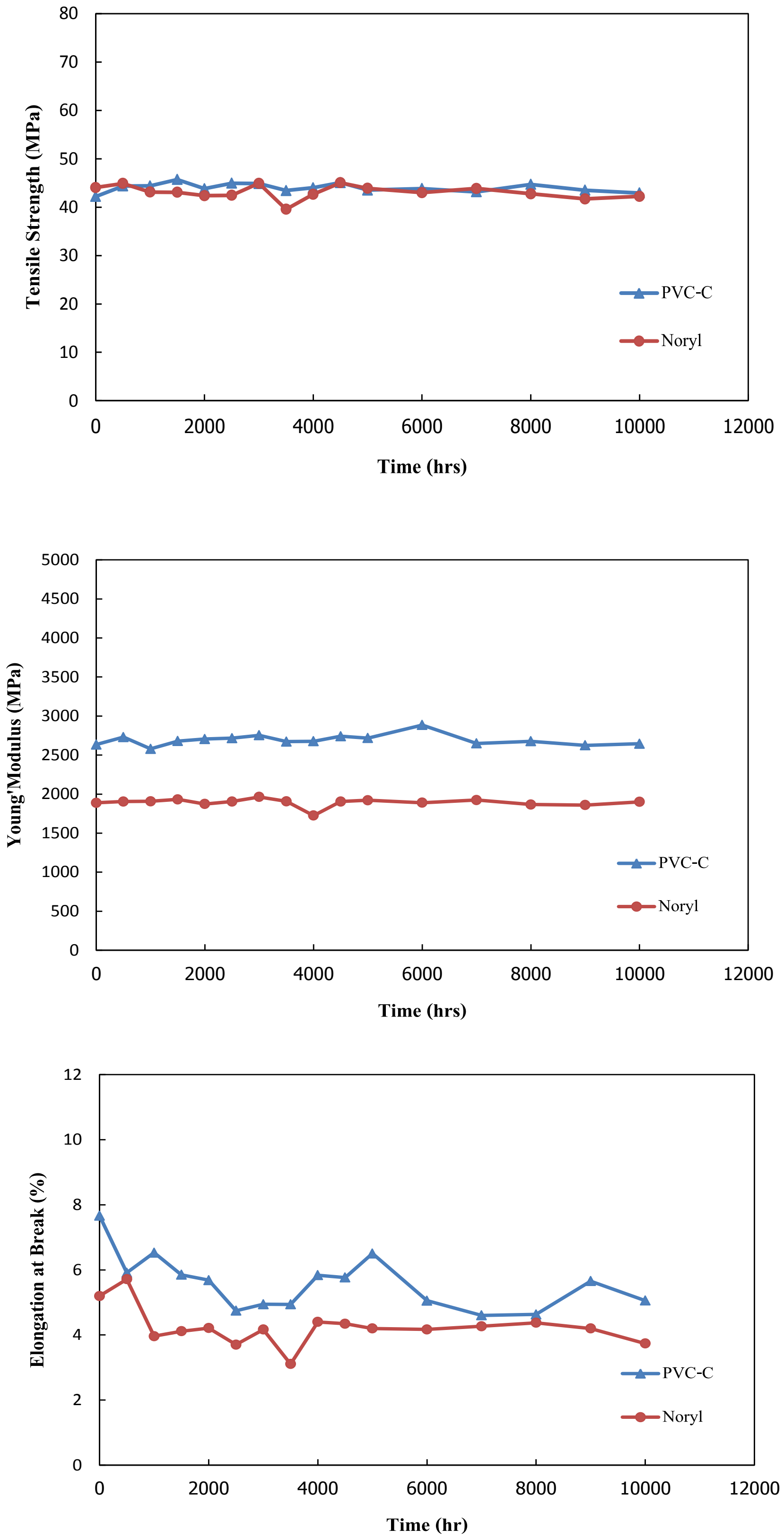


Fig. 5. Tensile strength, Young' modulus, and elongation at break after accelerated weathering test for 10,000 hours of PVC-C and Noryl.

4. Conclusion

The aging properties for PVC-C and Noryl were studied by measuring tensile strength, modulus, and elongation at break. The thermal efficiencies of PVC-C and Noryl were 50 % and 40 %, respectively. The lifetime expected from the aging results for PVC-C is more than 8 years of durability under these experimental testing conditions. It is worth noting that prices of extruded PVC-C are lower than Noryl, by about 10 times. Therefore, it is possible to produce solar collectors from polymer composite materials, cheaply.

5. Acknowledgment

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References

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

[2] Weiss, W., Bergmann, I., and Faninger, G., Solar heat worldwide: Market and contribution to energy supply 2005, International Energy Agency Solar heating and Cooling Program, Austria, 2007.

[3] Olivares, A., Rekstad, J., Meir, M., Kahlen, S., and Wallner, G.M. Degradation model for an extruded polymeric solar thermal absorber, Solar Energy Materials & Solar Cells, Vol. 94, No.3, pp. 1031–1037, 2010.

[4] Saeneerattanapraune, N., Taweekun, J., Kooptarnond, C. and Ngamsritragul, P. A study on efficiency of solar collector for hot water generation using EnergyPlus program, Proceeding of the 21st Conference of Mechanical Engineering Network of Thailand (ME-NETT), Chonburi, Thailand, pp. 1282-1287, 2007.

[5] Maneewan, S., Ponkaew, N., and Ketjoy, N. Comparison of flat plate solar collector performance: the different cover and absorber plate. Proceeding of the 3rd Conference on Energy Network of Thailand (E-NETT3), Bangkok, Thailand, pp. 1-8, 2007.

[6] Kohl, M, Jorgensen, G., Brunold, S., Carlsson, B., Heck, M., and Moller, K. Durability of polymeric glazing materials for solar applications. Solar Energy. Vol. 79, pp. 618-623, 2005.

[7] Hirunlaph, J., Chantawong, P., and Khedari, J. A simple-low cost solar water heater for Thailand. KMUTT Research and Development Journal, Vol. 23, No. 3, pp. 109-120, 2000.

[8] ASHRAE Standard 93-77, Method of testing to determine the thermal performance of solar collectors. New York: The America Society of Heating, Refrigerating, and Air Conditioning Engineers, pp. 1-33, 1978.

[9] American Society for Testing and Materials, A standard practice for operating fluorescent light apparatus for UV exposure of non-metallic materials. ASTM G 154, 2003.