Solar Energy 149 (2017) 272–284

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Solar pavement: A new emerging technology

Azin Sadeghi Dezfooli [a], Fereidoon Moghadas Nejad [b,*], Hamzeh Zakeri [c], Sholeh Kazemifard [d]

[a] Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Dep. of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran
[c] Member of Amirkabir Artificial Intelligence and Image Processing Lab (Attain), Dep. of Civil and Environment Engineering, Amirkabir University of Technology, Tehran, Iran
[d] Member of Amirkabir Renewable Energy Lab, Dep. of Chemistry, Amirkabir University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 22 November 2016
Received in revised form 21 March 2017
Accepted 8 April 2017

Keywords:
Solar pavement
Power conversion efficiency
Photovoltaic cell
British Pendulum Test
Universal test machine
Drainage test

ABSTRACT

The present work is conducted to evaluate the feasibility of using solar pavements as a sustainable energy producer to supply electrical energy. For this purpose, we prepared two prototypes entitled as "solar panel" (solar cell embedded in rubber and Plexiglas) and "solar pavement" (solar cell embedded between two porous rubber layers) which both are capable of harvesting and converting the solar energy into photovoltaic cells. In this work, components of the new solar pavements were introduced. These two designed pavements were evaluated in terms of supply energy, surface safety movement, and structural performance. The British Pendulum Tester (BPT) and Universal Test Machine (UTM) were used for measuring surface frictional properties and determining the dynamic property of solar pavement, respectively. Moreover, the drainage test was investigated for both prototypes. To survey the feasibility of solar pavement to achieve the electrical energy through solar cells, I-V (current-voltage) measurements were carried out to record the current and voltages of the solar cells embedded in the pavement under different conditions and determine their power conversion efficiency (PCE). The BPT values for solar panel and solar pavement under the wet condition were measured as 42 and 47.8, respectively. Also, the drainage test showed that the average volumetric flow rates of solar panel and solar pavement are 0.018 and 0.042 L/s, respectively. Moreover, the value of drainage test was 0.0224 L/s in asphalt pavement. The solar pavement in comparison to solar panel showed a higher PCE value of 5.336%. Besides, based on the UTM results, the flow number (FN) is 1002 with 49 mm deformation for solar panel and 1260 with 65 mm deformation for solar pavement. The UTM results also showed that solar pavement improves rutting performance in comparison with a solar panel. Thus, adding a new layer of the solar cell and rubber solar pavement could enhance strength parameters and electricity generation for transportation application.

1. Introduction

Pavement is one the main components of roads, as the essential global transportation infrastructures, that can potentially generate a substantial amount of energy (Nik et al., 2016). Also, energy issue has been a concern for researchers and industries. In this regard, the efficient use of renewable energy is considered the key to solving the energy problem and promoting the sustainable development of the society. Using renewable energy resources has become one of the essential steps to achieve sustainable development. As a result, many countries have issued some policies to encourage the utilization of renewable energy in various sectors (Yuan et al., 2013).

Although non-renewable fossil fuels supply 80% of the requirements of energy, this type of energy is about to be exhausted. Therefore, it is required to develop technologies for the application of renewable resources (Wang et al., 2006). Among the renewable energy resources, solar energy is an abundant and maybe eternally renewable energy source that generates 1027 KW energy from the sunshine. Solar energy can be harnessed by the implementation of solar heating, solar photovoltaic, solar thermal electricity, solar architecture, and artificial photosynthesis (Liu et al., 2014).

Todays, solar energy use has been improved by different technologies and many projects have been carried out to enhance the efficiency of all energy-producing applications (Kaçan et al., 2015; Fathabadi, 2015; Ferreira et al., 2015), including energy storage in the form of solar, wind, and thermal energies (Zheng et al., 2015; Rahimi et al., 2015). Numerical and experimental studies have been carried out on analysis, modeling, and simulation of solar energy to accumulate performance and management on the

* Corresponding author.
E-mail addresses: sadeqi_azin@yahoo.com (A.S. Dezfooli), moghadas@aut.ac.ir (F.M. Nejad), h-zakeri@aut.ac.ir (H. Zakeri), sh.kazemifard@aut.ac.ir (S. Kazemifard).

http://dx.doi.org/10.1016/j.solener.2017.04.016
0038-092X/

photovoltaic system (Shah et al., 2015; Reyes et al., 2015; Masiukiewicz and Anweiler, 2015). Research studies showed an exponential growth of cumulative nameplate capacity in watt DC (watt-peak since 1992–2015) has been boosted from 100 Mw in 1992 to 120,000 Mw in 2015 (Rekinger and Thies, 2015).

The growing communications and development of transportation system introduce environmental pollution; besides, a huge amount of energy is needed to supply power for transportation systems. These systems have significant impacts on the environment as the account for 20–25% of the world energy consumption and carbon dioxide emissions. Greenhouse gas emissions from transportation are increasing at a faster rate than any other energy-using sector. Road transportation is also a major contributor to local air pollution and smog (Samberg et al., 2011). Therefore, attention to problems such as environmental pollution, indiscriminate use of energy, damage to the environment and civic transportation risks, and use of sustainable development is necessary. Sustainable development in the transportation system will be feasible through managing the energy systems. One of the most important factors for urban management around the world is the correlation between sustainable development and operating renewable resources around the world.

Road surfaces absorb a great deal of solar radiation during summer, approximately up to 40 MJ/m^2 per a day, over the course of a road, leading to high temperatures in the pavement structure (Zhou et al., 2013; Hall et al., 2011). Therefore, pavement as an infrastructure of transportation and roads as the main artery can play an important role in achieving sustainable development in societies for reducing pollution and sustainable energy consumption.

Recently, implemental studies have been carried out to achieve green roads, such as bituminous asphalt containing waste material and solar asphalt to harvest sun energy and generate heat on the surface. In this respect, scientists believe that it is possible to harvest energy from sunlight on the roads and convert it into electrical energy and heat. The focus of previous works on solar usage in roads for gaining heat energy is to use asphalt pavement as a solar thermal collector. The first idea of the asphalt solar collector dates back to 1979 (Lund, 2005). One of the early applications of asphalt solar collector as a snow-melting system is the Swiss system SERSO. Gaia Snow-Melting System, similar to SERSO, was an automatically operating system installed in 1995 in Ninohe, Japan (Gao et al., 2010; Bobes-Jesus et al., 2013). There are several studies on implementation of asphalt solar collectors as snow melting systems and a mathematical model for predicting the performance of this smart pavement based on modeling. Also, laboratory researches done on the behavior of pavement as a solar collector, heat analysis, heat transfer (Tu et al., 2010; Shaopeng et al., 2011; Larsson and Thelandersson, 2011).

Conversion of solar energy radiated on the surface of the road is a desirable technique to reduce environmental pollution; and supply energy requirements of variable message signs (VMS), road lightening, and traffic signal (Donaghy and Schintler, 1998). Recently, some surveys have been exclusively conducted on solar roads. Brusaw (2012) in Idaho, U.S., designed an electrical system with added light emitting diodes (LEDs) for road lines that lighted up the road for safer driving at night. These researchers also designed a heating element on the surface (like the defrosting wire in the rear window of cars) to prevent snow/ice accumulation in cold climates. The Solar Roadway is an intelligent highway system that is equipped with a controller consisting of a microprocessor unit that activates the lights and communicates with the road panels. They extend their research to build a parking lot to melt snow (Brusaw, 2012).

Northmore and Tighe (2012) at Waterloo University used laminated, tempered, and textured glass to boost strength and illustrate the solar panel as a solar road. George Washington University has made a solar road with Onyx glass for a pathway (George Washington University website).

García and Partl (2014) are represented how to transform an asphalt concrete pavement into a solar turbine for absorbing solar energy from the surface of asphalt concrete. This solar turbine could be used to harvest energy and to reduce the temperature of the pavement in summer or to increase it in winter. In order to achieve this purpose, air conduits were embedded in an asphalt concrete, such that air could flow and be heated up in summer, or cooled down in winter.

Zhou et al. (2015) are studied the effectiveness of pavement solar energy system in an experimental study. In this research, a small-scale pilot project was built for the pavement-solar energy utilization. The results of their work showed solar pavement can saves the energy for ice/snow removal but also mitigate associated safety risks.

Nasir et al. (2016) presented a solar pavement based on solar collectors for urban applications. This study expanded the investigation of optimizing the solar pavement collector system based on four tested parameters (pipe diameter, pipe depth, water velocity, and water temperature) and results showed saving energy by solar collectors.

Efthymiou et al. (2016) developed a photovoltaic pavement system for heat island mitigation. The results were checked by a theoretical mathematical model. The whole measuring campaign indicated that lower temperatures were measured on the PV pavement than those measured on the other two materials (soil, asphalt). The numerical predictions are compared with the experimental data where similar results are founded. The results showed photovoltaic cells saved energy for pavement system.

Chiarelli et al. (2017) presented a research about construction and configuration of convection-powered asphalt solar collectors for the reduction of urban temperatures. In this research, an analysis of a convection-powered asphalt solar collector prototype is approached by the means of experimental trials and computational fluid dynamics (CFD). The results obtained are showed that for an overall optimal performance, pipes should be installed in a single row under the pavement wearing course. This allowed a surface temperature reduction of up to 5.5 °C in the pavement prototype studied and the highest absorbed energy. In addition, the CFD simulations showed that care has to be put in finding the optimal shape and size for the air collection chamber, as they significantly influence the behavior of the system.

Therefore, the idea of constructing solar pavement is a novel field of civil engineering that requires more studies and technological advancements. The purpose of this study is to evaluate the feasibility of implementing solar roads as a sustainable energy.

In this study, a novel design of energy generator pavement is introduced. The proposed system works based on the implementation of layers consisting of solar cells and an electrical system on the asphalt layer. This sustainable development method can cover both electrical energy requirements and safety in the roads. The general design of solar pavement consists of three layers. The first layer, on which vehicles could drive, is a transparent and porous surface that passes the sunlight. The second layer consists of solar cells, an electrical system, connections, and a base to transfer the load to asphalt. These layers are incorporated and placed on the asphalt. Finally, the samples are compared together and the feasibility of each specimen under different conditions is surveyed. Laboratory tests include the British Pendulum Tester (BPT) for measuring surface frictional properties and Universal Test Machine (UTM) for determining the dynamic property of solar pavement. Moreover, the drainage test for two prototypes is investigated in this work. To survey the feasibility of solar pavement to achieve the electrical energy through solar cells, current-voltage (I-V) measurements are carried out.