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How to transform an asphalt concrete pavement into a solar turbine

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HIGHLIGHTS

- We create a system for harvesting energy from asphalt concrete.
- We create an artificial porosity in the asphalt concrete.
- We connect a chimney to this porosity.
- Differences in temperature produce an air flow.
- This air flow serves also for cooling down the pavement.

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ABSTRACT

Asphalt concrete can absorb a considerable amount of the incident solar radiation. For this reason asphalt roads could be used as solar collectors. There have been different attempts to achieve this goal. All of them have been done by integrating pipes conducting liquid, through the structure of the asphalt concrete. The problem of this system is that all pipes need to be interconnected: if one is broken, the liquid will come out and damage the asphalt concrete. To overcome these limitations, in this article, an alternative concept is proposed:parallel air conduits, where air can circulate will be integrated in the pavement structure. The idea is to connect these artificial pore volumes in the pavement to an updraft or to a downdraft chimney. Differences of temperature between the pavement and the environment can be used to create an air flow, which would allow wind turbines to produce an amount of energy and that would cool the pavement down in summer or even warm it up in winter. To demonstrate that this is possible, an asphalt concrete prototype has been created and basics calculations on the parameters affecting the system have been done. It has been found that different temperatures, volumes of air inside the asphalt and the difference of temperature between the asphalt concrete and the environment are critical to maximize the air flow through the pavement. Moreover, it has been found that this system can be also used to reduce the heat island effect.

1. Introduction

Pavements can be used as solar collectors. This has been shown for concrete [1] and for asphalt roads [2] in different places around the world [3–8]. Moreover, they may reduce the heat island effect [9]. Actual pavements working as solar collectors often consist of a serpentine or in a porous surface [10] embedded in the pavement with a circulating fluid inside. They need a surface with a very high absorptivity and the ability to transport heat, for example by the flow of liquid to transfer the heat. To reach the maximum efficiency, the flow regime inside the serpentine has to be turbulent. Furthermore, it has been recommended that the pipes in the serpentine should be made of copper, for a very high thermal transfer [9]. Besides, this kind of collectors cannot be constructed in roads subjected to high traffic intensities or high traffic loads, because they will be in risk of being damaged [2]. Moreover, these roads may present problems of maintenance, as in case the serpentine breaks it may be difficult to repair [11]. In addition, road repair with such systems may be difficult making such systems not suited for urban regions where roads have to be opened for laying new supply lines in temporary trenches. In winter regions the fluid in the pipes may also be damaged from frost.

On the other hand, solar updraft towers and solar chimneys are a special type of solar collector. They consist of an air heating system with a very high absorptivity, connected to a chimney [12]. During the day, air will be heated, creating an updraft of air

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through the chimney. As a result, convection causes air to rise up the chimney, which allows wind turbines to produce electricity [13]. Furthermore, this air flow may also be used to enhance the stack ventilation through a building [14]. The problem of these systems is that they have a very low efficiency for producing electricity [15], although they may work very well for creating a natural regulation of temperature in a building [16].

An alternative way of harvesting energy could be reached by creating an artificial air flow through parallel air conduits embedded in the asphalt concrete pavements structure, where air could circulate and be heated up in summer, or cooled down in winter. By connecting these air conduits to an updraft or to a downdraft chimney, temperature differences between the pavement and the environment can be used to create an air flow, which would allow wind turbines to produce an amount of energy and that would cool the pavement down in summer or heat it up in winter. Such a system would not create any damage in the asphalt when leaking air (although this would affect the efficiency of the system). The air conduits could be placed such that they could provide some reinforcement in the asphalt concrete layer. When opening a road for temporary trenches, the system could be repaired in an easier way than with a fluid conducting system. The reason for this is that in the case of air conduits embedded in the pavement, these do not need to be connected among them. In urban region, the chimneys with the wind turbines could be easily integrated in street lightening posts.

The objective of this paper is to present a first proof of concept on this system, showing the main influence parameters and discussing the results with a first demonstrator. For that, the steel tubes were embedded in an asphalt concrete material and the chimney has been simulated through PVC pipes (see Fig. 1). Additionally, the air flow and the reduction of temperature have been taken as indicators of the energy harvested by the pavement. Finally, the effects of changing the height of the chimney, the porosity of asphalt concrete and the influence of the air flow on the total temperature of the pavement have been analyzed.

2. Experimental method

2.1. Materials and test specimens preparation

A dense asphalt concrete mixture AC8 with 70/100 pen virgin bitumen was used in this research. The aggregates consisted of crushed basaltic material (size between 2 mm and nominal maximum aggregate size of 8 mm and density 2770 kg/m^3), crushed sand (size between 0.063 and 2 mm and density 2688 kg/m^3) and filler (size < 0.063 mm and density 2638 kg/m^3).

The air conduits were created through 60 steel tubes embedded in the mixture (see Fig. 1(b)), which were 30 cm long and had 9 mm internal diameter, and 11 mm external diameter. They were placed at 4 different levels, with 15 tubes in each level, separated 1 cm in the vertical and 2 cm in the horizontal direction. These tubes are equivalent to a connected porosity in the asphalt concrete of 8.5%.

Moreover, the asphalt concrete prototype was covered with extruded polystyrene foam, for thermal isolation purposes, leaving only the upper surface exposed to the infrared lamps which simulated the solar energy source. In order to simplify the calculations, the objective was that the temperature of the pavement could be considered approximately constant. The area of the upper surface was 45 cm × 30 cm. Besides, two air chambers of 10 cm × 10 cm × 45 cm were created at both sides of the test specimen, at the entrance and the exit of the air conduits, such that the air could circulate through all the asphalt concrete (see Fig. 1(b)). Each chamber was sealed with epoxy resin.

Finally, a hole of 5 cm diameter was opened in each air chamber and in one of them, an updraft chimney was connected. Chimneys were 5 cm diameter PVC pipes of 0.2 m, 0.5 m, 1 m, 1.5 m and 2 m length.

2.2. Test specimens preparation

Approximately 50 kg of the dense asphalt mixture were used for preparing the energy-harvesting asphalt concrete prototype. This material was divided in 4 batches of 9 kg and in 1 batch of 14 kg. Before the compaction, the 14 kg batch was firstly placed on the bottom of the mould. On top of the asphalt concrete, the first layer of air conduits was placed. Then, the first 9 kg asphalt concrete batch and the second layer of tubes and successively until the end of the material.

After this process, the material was compacted by using a pneumatic laboratory wheel compactor [17]. From this procedure, a prismatic test sample of 40 cm × 50 cm × 10 cm was obtained. Finally, the prismatic specimen was saw cut for obtaining a 30 cm × 45 cm × 10 cm specimen.

2.3. Temperature measurements

Different temperatures above the environment temperatures were reached in the asphalt concrete test specimen by placing

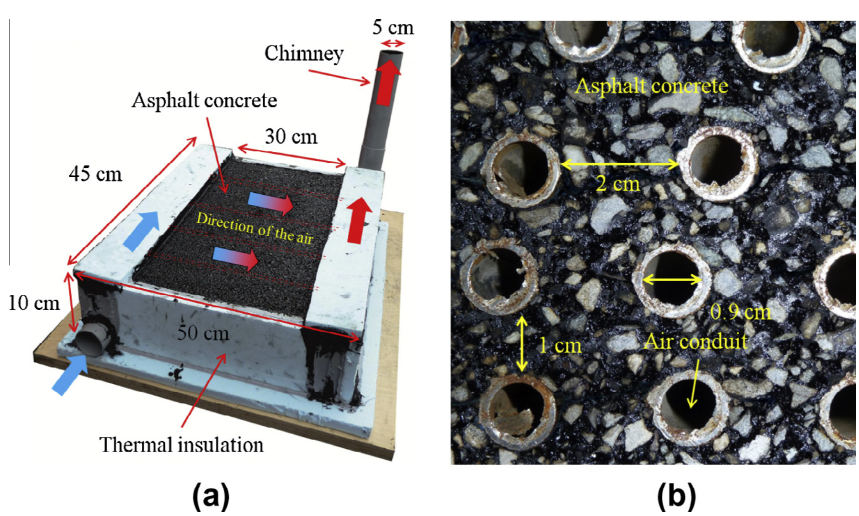

Fig. 1. (a) Scheme of the prototype. (b) Detail of the air conduits in one side of the prototype.