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Experimental investigation into the thermal behavior of wearing courses for road pavements due to environmental conditions

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HIGHLIGHTS

- Both air temperature and solar irradiance greatly affect road pavement temperatures.
- Air humidity and wind have no significant effects on road pavement temperatures.
- Heat transfer increases passing form light to dark colored pavement surfaces.
- Dark colored pavements are greatly affect by solar irradiance.

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ABSTRACT

This paper reports the results of an investigation focusing on the evaluation of the effects of environmental conditions on five materials currently used in Europe for wearing courses for urban road pavements. The investigation lasted one year and was carried out on paving slabs. Environmental conditions and pavement temperatures at two depths from the surface were measured, analyzing the effects of air temperature on pavements throughout the whole period of observation and during the hottest and coldest days. The study shows the potential of lighter colored pavements used in urban areas to mitigate the Urban Heat Island phenomenon.

1. Introduction

The reduction of global warming is now a key issue to which many nations worldwide have been addressing their environmental policy. Moreover, the mitigation of global warming effects is considered mandatory for those countries committed to reducing greenhouse gas emissions by signing the Kyoto Protocol.

Nations have several tools for achieving this goal, acting at different levels, from citizens' daily behavior to domestic, industrial policies. Urban areas play a crucial role in this context, as cities are one of the most important causes of the warming effects. These areas are warmer than the surrounding rural areas and, especially during summer, very high temperatures cause an increase in energy consumption, air pollution and health issues.

One of the main, contributing factors of the Urban Heat Island (UHI) effect is related to construction materials, and particularly to their ability to transfer heat. In this contest, urban road pavements play an important role in warming effects as they are currently made of asphalt concretes, characterized by their notable capacity for transferring heat due to their dark color.

Presently, although much research has dealt with this topic, there is a lack of knowledge about the real effects of road pavements on urban warming. Most studies available in literature provide few models on a city scale or for laboratory testing, or on site measurement has been collected over a period of less than a month. For these reasons, the investigation discussed in this paper focuses on the assessment of climatic effects on five different road pavements. As such, the paper provides an overview of a year of on-site observations and describes some details of the specific protocols followed during the research project.

2. Background and goals

So-called cool pavements have been defined as a wide range of innovative materials having lower surface temperatures compared to conventional products [1]. Although much experimental data is available to evaluate the performance of cool materials in isolated buildings [2–4], little information is accessible regarding reflective

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materials utilized in open urban areas [5–7] and especially in cool pavements.

Many studies have been conducted on light colored, high albedo (or solar-reflective) materials for buildings and roads, in order to mitigate the urban temperatures and therefore reduce the Heat Island effect [8–14].

In the past, researchers have demonstrated that cool roofs with high solar reflectance and emissive power should be adopted to reduce energy consumption for cooling and pollutant concentrations [2,3,15]. On the other hand, many studies lead to the development of reflective pavements light-colored surfacing materials which lower the pavement surface temperature compared to conventional black asphalt [1,4,16–22]; moreover a substantial difference of 10–20 °C between the air temperature and painted specimens has been noted in literature [18,23].

New generation, reflective, colored pavements using infrared reflective pigments present a much higher reflectivity in the infrared part of the spectrum compared to conventional materials of the same color, resulting in an overall higher solar reflectance and in an important reduction of surface temperatures [2,16–19,21,23–25].

Since highly reflective materials have a high cooling potential during the summer period (though they may increase the heating needs of buildings), coatings with dynamic optical characteristics have been developed: these materials can change their reflectivity as a function of the ambient temperature or solar radiation intensity, adapting to the specific needs and conditions [19].

The use of thermochromic coatings is another potential strategy for decreasing the Heat Island effect. These materials are able to change their colors in response to temperature, in order to make pavement more reflective during summer and solar absorptive during winter [20,26,27]: thermochromic coatings in the colored phase (below the transition temperature) are energy-absorbing, while in the colorless phase (above the transition temperature) they are energy-reflecting.

Furthermore, coatings prepared with the addition of TiO_2 as a photocatalyst (lighter tones) are reported in literature as materials able to mitigate the effects of heat [20].

In addition, the performances of organic Phase Change Materials (PCMs) when incorporated in cool pavements are studied in the literature, demonstrating that PCM coatings transfer heat in a latent form, maintaining constant surface temperatures [21].

Some researchers consider permeable (porous) pavements as potential cool pavements because the voids of the pavement allow evaporative cooling [1,22]. Other studies demonstrated that porous asphalt has the highest daytime surface temperatures and lowest night time temperatures, when compared to other materials with similar or higher Albedo [28].

Even conventional concrete pavement (PCC) may be considered a potential cool pavement because of its light color and high solar reflectance. Other researchers also propose open-graded asphalt concrete in which voids are filled with a cement mortar as cool pavements, demonstrating that the maximum surface temperature of the pavements fell by 8–10 °C if compared to standard asphalt concrete pavement [29].

Another significant effort towards Heat Island reduction is the research concerning the degradation of the paint surface and the methods for maintaining performance of high-reflectivity paint [24].

To summarize, a large number of laboratory studies on several road materials that analyze the Urban Heat Island effect can be found in literature; however testing procedures took place over short experimental periods (usually a day) and were characterized by ambient climatic conditions very far from real urban environments. Few other studies have recorded data considering environmental conditions and the research that exists does not describe analysis periods of longer than a month.

On the basis of the above-mentioned literature review, the aim of the research described in this paper is to evaluate UHI effects on five different road pavements currently used in Europe. The pavements considered include dense and porous asphalt concretes, also treated using a sprayed photocatalytic coat, and an open grade asphalt concrete filled with cement mortar. The pavements were selected in order to investigate their heat transferring ability relative to their surface color, density, and voids. The investigation was performed on site and lasted one year. Climatic measurements, including air temperature, relative humidity, wind speed, and global solar radiation were recorded. Pavement temperatures at two depths from the surface were measured. Acquired data was used to analyze both the relative effects of air and pavement temperatures during the entire period of observation, and to highlight the daily effects of environmental conditions (air temperature, solar irradiance, relative humidity and wind speed) on the specimen temperatures. For this reason, this stage of the data analysis concentrated on the hottest and coldest days of the observation period.

3. Materials, experimental program and methods

3.1. Materials

In the experimental investigation described in this paper, five different mixtures commonly used as wearing course in urban road pavements were selected:

- a dense-graded asphalt concrete (following named DG);
- an open-graded asphalt concrete (OG);
- a dense-graded asphalt concrete, the same as for DG, sprayed with a photocatalytic emulsion with a titanium dioxide base (DG/S) at rate of 350 g/m^2;
- an open-graded asphalt concrete, the same as for OG, sprayed with a photocatalytic emulsion with a titanium dioxide base (OG/S) at rate of 350 g/m^2;
- an open-graded asphalt concrete filled with a cement mortar (OGWM), in which voids are filled with a blend of cement and titanium dioxide microcrystal, 27% water and water/cement ratio of 0.43.

Fig. 1 shows the sieve size distribution of the aggregates used for DG, OG DG/S and OG/S mixtures and for OGWM mixture as well. Bitumen types and contents are given in Table 1.

Each mixture was used to compact specimens (slabs of 30 cm in length, 20 cm wide, and 5 cm thick) using a laboratory Roller Compactor [30], except for the OGWM mixture which was drilled by a test track used for a previous research study [31]. The volumetric properties (Air Voids, VFA, VFB) of each slab are given in Table 1.

3.2. Experimental program and methods

In order to subject the tested pavements to the environmental conditions of a European urban road, the corresponding five specimens were placed on a terrace sufficiently far from other buildings, to avoid shadow effects, at the Politecnico di Milano in the city centre. As shown in Fig. 2, the slabs were placed on the top of a wooden formwork (160 cm in length, 80 cm wide, and 25 cm thick), using granular materials to separate them from the edge and the bottom of the formwork. This allowed the creation of a sort of subgrade under the specimens and a boundary effect on the edge of them. To prevent rain accumulation in the formwork, the bottom of this was drilled to allow rainwater to percolate. PVC pipes were used

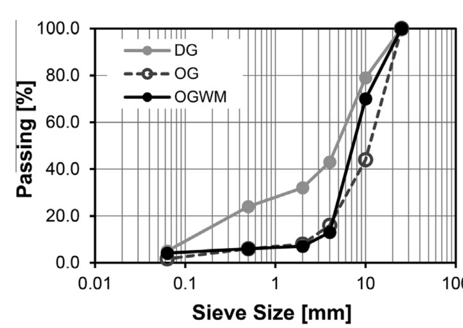

Fig. 1. Aggregates sieve size distribution.