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Aging albedo model for asphalt pavement surfaces

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ABSTRACT

One of the most significant factors affecting pavement-induced Urban Heat Islands is the albedo. Several studies have shown albedo's effect on air temperature and building energy usage. Albedo depends on the optical properties of the material constituents of the surface layer of the pavement, which can change over time or with additives. The albedo of a series of full-scale asphalt and concrete pavement test sections of varying ages in Rantoul, Illinois (USA) was measured and a non-linear aging albedo model for asphalt pavements was developed. For a hypothetical pavement section, the current practice of assuming a constant albedo over time was found to overestimate the Global Warming Potential of the asphalt pavement by about 25%. In addition, the albedo of translucent polymer fibers was determined to be 0.07 using a spectrophotometer. This does not have a thermal impact on the pavement as long as the fibers remain coated with cement paste. However, if the fibers become exposed because of abrasion, they will have an impact on albedo depending on the pavement area containing exposed fibers.

1. Introduction

Rapid urbanization around the world in the last century has led to the replacement of natural materials by man-made ones through the construction of buildings and pavements. This has had consequences for the urban heat budget and local climate. The Urban Heat Island (UHI), characterized by high urban temperatures with respect to adjacent rural areas, is one such consequence that has been studied in great detail (Kleerekopera et al., 2012; Memon et al., 2008; Oke, 1982; Pichierri et al., 2012). Previous studies have demonstrated that temperature increases because of the UHI leads to potentially higher water consumption (Aggarwal et al., 2012; Guhathakurta and Gober, 2007) and building energy usage (Taha et al., 1988).

With respect to UHI mitigation, cool pavements, among other solutions, have been the subject of extensive research, with several materials having been proposed to lower pavement temperatures (Boriboonsomsin and Reza, 2007; Li et al., 2013b; Santamouris et al., 2011; Santamouris, 2013; Santero et al., 2011). The common feature of all these proposed materials is that they increase the albedo of the pavement, which is the average reflectance of the material over the solar spectrum and varies from 0 (no reflection) to 1 (perfect reflector). Studies have shown that the impact of albedo on UHI can vary from about 1 to 100 t CO_2-eq/lane-km of pavement (Santero and Horvath, 2009) and a global adoption of cool roofs and pavements can lead to a potential offset of 44 Gt CO_2-eq (Akbari et al., 2009). A review of literature by Taha (1997) placed albedo as among three factors affecting the surface energy balance of urban surfaces, the other two being evapotranspiration and anthropogenic heat. It was found from field studies as well as simulation that albedo can be an effective tool in modifying the near-surface climate, although a more recent review of literature (Yang et al., 2015) indicated that increasing albedo may have some undesirable outcomes in terms of regional hydroclimate, thermal comfort, and air quality. Thus, the surface layer albedo assumes a prominent position in the study of UHI mitigation.

In general, pavement surfaces are either made of Asphalt Concrete (AC) or Portland Cement Concrete (PCC) with several studies measuring the albedos of both kinds of pavements. The albedo of freshly-paved asphalt has been measured to be 0.04 to 0.06 (Li et al., 2013a; Taha et al., 1992), which rises to 0.09 to 0.18 after environmental aging (Santamouris et al., 2011). As noted, asphalt pavements initially have a very low albedo, but with aging and aggregate exposure, it eventually increases significantly (Tran et al., 2009). There has been little effort to understand how quickly this aging occurs and consequently, most UHI studies assume a single, static value of albedo over the service life of the asphalt pavement (Li et al., 2014; Menon et al., 2010; Munoz et al., 2010; Yu and Lu, 2014; Yaghoobian and Kleissl, 2012). Even the new AASHTO

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(2015) mechanistic-empirical pavement design guide recommends a default value (static) of 0.15 for AC and 0.30 for PCC.

The albedo of a newly cast concrete pavement is higher than that of a new asphalt pavement, at about 0.20–0.30 (Li et al., 2013a). This albedo value is highly sensitive to the choice of cement, aggregates and supplementary cementitious materials, which can increase the albedo of new concrete to 0.50 to 0.70 (Boriboonsomsin and Reza, 2007; Levinson and Akbari, 2002). While carbonation initially increases the albedo of concrete, it eventually decreases by about 0.06–0.19 because of weathering, soiling, and abrasion (Levinson and Akbari, 2002). Thus, concrete albedo has the opposite trend to asphalt pavement with higher albedo at construction and decreasing over time (Santero et al., 2011).

In addition, supplementary materials used in concrete can alter the surface characteristics and potentially the albedo of the pavement. In particular, fiber-reinforced concrete has been extensively used to improve the toughness and achieve higher durability of the concrete mix (Balaguru and Shah, 1992; Bordelon and Roesler, 2011). Organic fibers have been used in cementitious roof tiles for cheaper construction in rural areas with measured albedos of 0.30 (Roma et al., 2008). No research has been reported on the albedo of fiber-reinforced concrete pavements where the fibers are visible at the slab surface.

From the literature, albedo for both concrete and asphalt pavements is found to be a property that depends on a variety of factors including age and surface material constituents. Pavement albedo can vary spatially as well as temporally but this is not currently incorporated in the use phase analysis of pavement life cycle assessment (LCA) studies (Santero et al., 2011). This paper reports the results of albedo measurements for a set of asphalt and concrete pavement test sections of varying ages in Rantoul, Illinois (USA). From the asphalt pavements, a non-linear aging albedo model is proposed and used to determine the Global Warming Potential (GWP) of a hypothetic pavement as compared to one with a static albedo. In addition, a spectrophotometer is used to determine the approximate AM 1.5G albedo of polymer fibers used in and visible on the surface of one of the concrete pavements to understand whether this surface modification has a significant impact on the albedo of the pavement.

2. Materials and methodology

2.1. Test sections

The University of Illinois operates the Advanced Transportation Research and Engineering Laboratory (ATREL) in Rantoul, which includes several full-scale test sections, each about 150 m in length. The full-scale test sections, seen in Fig. 1, include both concrete and asphalt and were built over the past 8 years in what is called the Accelerated Transportation Loading Assembly (ATLAS) facility.

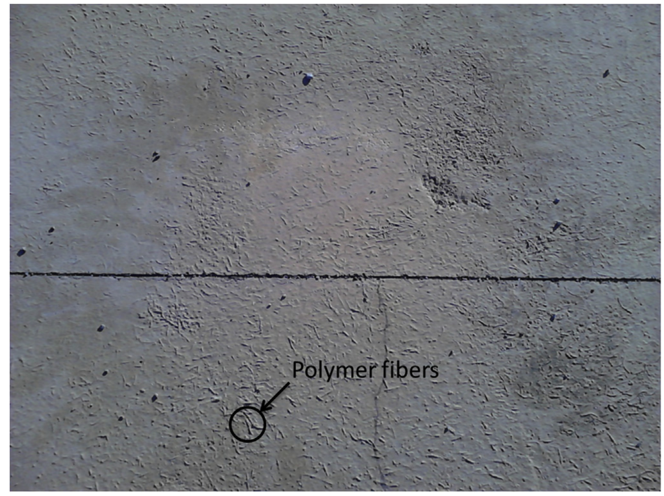

Fig. 2. Top view of PCC1 with polymer fibers on the surface.

As of October 2014, the ATLAS facility had five sections – three asphalt and two concrete – that were constructed over the years and exposed to continuous weathering. These sections are named AC1 to AC3 for the asphalt sections and PCC1 and PCC2 for the concrete, as shown in Fig. 1. Towards the east end of AC2 is an asphalt overlay that was recently constructed. PCC1 is a 5 cm concrete inlay made of Flowable Fibrous Concrete (FFC) (Bordelon and Roesler, 2011) over an old asphalt pavement. Polymer fibers used in PCC1 are visibly embedded in the surface (Fig. 2). In addition, at the time of construction, a curing compound was applied on the surface, which likely impacted the final color of the section. PCC2 consists of a short segment, about 12 m in length, that was built separately and for a different purpose than the rest of the section. The majority of PCC2 underwent repeated loading until fatigue failure and therefore only limited testing could be performed on it. The albedo of all these sections was not previously measured.

Table 1 lists the type of pavement, year of construction of the sections, and a reference with more details about paving materials, construction, and testing results. For the purpose of sampling albedo, each section was divided into subsections of about 15 m each. The designation of each is also shown in Table 1.

2.2. Albedo measurement

There are two methods reported in literature to measure albedo: field testing using an albedometer (also called a double pyranometer) (Li et al., 2013a) as per ASTM E1918 (ASTM International, 2006), which gives an accurate value for the location but is strongly dependent on size of the sample and weather conditions;

Fig. 1. Google Earth^{TM} screenshot of the ATLAS facility with the five sections under study labeled AC 1–3 and PCC 1–2.