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Applied Optics in the Development of Smart Asphalt Mixtures

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Abstract. The functionalization of asphalt mixtures is carried out in order to provide new capabilities to the road pavements, with major social, environmental and financial benefits. Optical characterization techniques as well as optical processes like photocatalysis play a major role in the development of new asphalt mixtures with smart functions. These advanced capabilities which are being developed in asphalt mixtures are: photocatalytic, superhydrophobic, self-cleaning, de-icing/anti-ice, self-healing, thermochromic, and latent heat thermal energy storage. The main objective of this research work is to stress the importance of optics and photonics technologies giving an overview of advanced functionalized smart asphalt mixtures.

1 Introduction

The road pavements must resist to vehicle traffic and climate actions, and also assure the rolling conditions with comfort, economy, and safety with low impact on the environment. Recently, the functionalization of road pavements and their multifunctional capabilities have become an important subject due to the large area covered by these roadways cover. Optical techniques are extensively used in order to design these smart asphalt mixtures. The literature has already shown important results in the functionalization of the asphalt road pavements and also the development of smart and multifunctional asphalt mixtures, mostly for the top layer. The main important smart and multifunctional capabilities applied to asphalt mixtures addressed in this work are: photocatalytic, superhydrophobic, self-cleaning, de-icing/anti-ice, self-healing, thermochromic, and latent heat thermal energy storage [1].

2 Photocatalytic Capability

Air pollution is one of the biggest environmental problems in urban centers. Road traffic is one of the most important sources. For this reason, the photocatalytic capability can be provided in asphalt mixtures. Semiconductor oxides, such as TiO_2, have the ability to oxidize pollutants, such as NO_x, SO_2, and also to degrade organic compounds in the presence of ultraviolet (UV) light, oxygen and humidity [2]. Spectrophotometric and gas chromatography techniques are used to analyze this capability.

3 Superhydrophobic Capability

On road pavements, the worst weather condition occurs when there is water or ice on the surface. Thus, it is important to drain or repel the surface water quickly. If the water droplets are repelled from the surface, the ice/snow formation is avoided [3]. This approach provides safer roads during rain and low temperatures by the application of superhydrophobic coatings containing Polytetrafluoroethylene (PTFE), TiO_2, SiO_2, among other particles. The surface roughness is a critical aspect that is analyzed by optical methods, including by optical triangulation based-microtopography [4].

4 Self-cleaning Capability

Self-cleaning is promoted in order to remove dirt particles or degrade organic compounds, i.e., oil and greases, over the surface, contributing to the reduction of accidents in oil spilled areas and also in dusty areas. The self-cleaning capability is achieved in three types of surface: i) superhydrophobic: water droplets roll on the surfaces and carry the dirt previously deposited, this phenomenon is called Lotus Flower effect, ii) superhydrophilic: water droplets are spread over the surface, which is more easily washed by removing adsorbed dirt on its surface during rainy periods, and iii) photocatalytic: the photocatalytic materials can degrade organic pollutants (like oils and greases), cleaning the surface.

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5 De-icing and Anti-ice Capabilities

As mentioned before, snow and ice in winter reduce road safety due to the reduced friction between tires and pavement. In order to mitigate this problem, numerous researches point to the use of de-icing agents and/or conductive materials in the asphalt mixtures [5,6]. The first one can melt the ice and snow from a chemical process. The other is associated with a microwave or an induction-heating process to melt the ice/snow.

6 Self-healing Capability

Cracking of the asphalt mixtures is one of the most important degradation processes. By using conductive materials, self-healing agents or nanomaterials, it is possible to develop the self-healing capability in order to close microcracks. This capability provides a longer lifetime to pavements, reducing the rehabilitation needs and, consequently, requiring less materials for paving, leading to less emission of CO_2, and traffic disruption [7]. Optical inspection is used in order to observe the cracking healing. Also, asphalt binder tests regarding rheology and mechanical tests concerning fatigue are carried out to evaluate the self-healing.

7 Thermochromic Capability

Thermochromic materials have been incorporated in Civil Engineering materials due to its change of optical and thermal properties. The Urban Heat Island (UHI) is an urban area that is significantly warmer than its adjacent rural areas due to human actions. By the introduction of thermochromic materials into the asphalt binder, the conventional black color is changed to another lighter color in order to reduce the energy absorption from sunlight, reducing the surface temperature. In this sense, thermochromic asphalt mixtures can mitigate the Urban Heat Island (UHI) and also improve mechanical and aging properties [8]. Spectrophotometric techniques are used to assess this capability.

8 Latent Heat Thermal Energy Storage (LHTS) Capability

A Phase Change Material (PCM) is a substance that presents a high fusion heat, melts and solidifies at a certain temperature, and is able to store/release large amounts of thermal energy. With the use of PCM, the Latent Heat Thermal Energy Storage (LHTS) capability is developed. When this technology is applied on asphalt mixtures, the UHI is mitigated, and their mechanical properties are improved by the reduction of the magnitude of temperature fluctuations [9]. By the increase of the thermal comfort in urban areas, there will exist social benefits besides the reduction of the energy consumption from heaters and air conditioners (lower use), consequently, decreased emissions.

9 Conclusions

This research work aimed to present a literature overview of smart and multifunctional capabilities applied to asphalt mixtures. A smart and multifunctional asphalt mixture is an intelligent material with different properties that differ from the conventional abilities or reacts upon an external stimulus, such as light irradiation, stress, and temperature. Optical characterization and analysis is used for its design. The roads have a large area that can provide benefits to the society and the environment, besides having a good mechanical structure and good superficial properties by the application of new capabilities. Moreover, the functionalization process of Civil Engineering materials can enhance the dynamism of the nanomaterials and nanotechnology industry due to the production and use in large scale. These sustainable surfaces can contribute to the “Green Recovery” model by developing smart materials that contribute to social, economic and environmental aspects.

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