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Aging of asphalt binder in hot pavement rehabilitation

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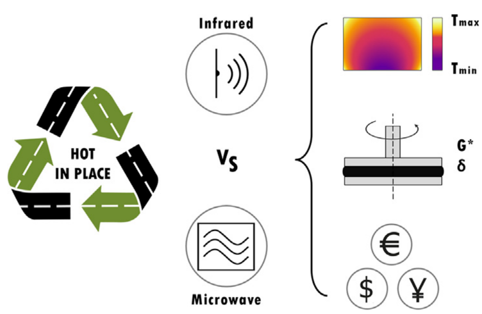
HIGHLIGHTS

- Two heating methods for asphalt pavements were compared: infrared and microwaves.
- The efficiency of microwaves is higher than that of infrared radiation.
- Thermographic analysis revealed a more homogeneous heating of asphalt mixtures with microwaves.
- The aging effect of microwaves on asphalt binder was less significant than the infrared one.

GRAPHICAL ABSTRACT



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ABSTRACT

Construction of new asphalt road pavements as well as traditional maintenance requires the use of a great amount of non-renewable resources, having important negative environmental and economic impacts. Thus, extending the service life and promoting the recycling or reuse of pavement materials represent two pillars of a sustainable development model. These strategies include also two approaches which involve heating and softening of the existing hot-mix asphalt (HMA) pavement, such as healing and hot-in place recycling. Modern and more efficient technologies potentially used for the on-site heating of flexible pavements are no longer based on electrical resistance systems but use microwaves or infrared radiant heaters, which can however lead to a further potential aging of asphalt binder and therefore negatively affecting the mechanical properties of recycled HMA.

This article aims, through an experimental laboratory approach, to directly compare two heating methods potentially used in flexible pavement rehabilitation, i.e. infrared and microwave radiations, for a preliminary assessment of the heating process characteristics (temperature distribution, energy consumption and duration) and on asphalt binder aging phenomenon. The thermographic and rheological analyses revealed that microwave radiation represents a more energy-efficient solution compared to infrared, producing minor aging effects on asphalt binder.

1. Introduction

Construction of new asphalt road pavements as well as traditional maintenance requires the use of a great amount of non-renewable resources, having important negative environmental and economic impacts. Thus, extending the asphalt pavement service life and promoting all the recycling strategies aimed to re-use reclaimed asphalt pavement (RAP), recycled asphalt shingle (RAS) or industrial by-products (tires, steel slags, glass) represent two pillars of a sustainable development model [1,2].

Strategies for maintaining or extending the flexible hot-mix asphalt (HMA) pavements design life include healing [3,4]. The healing of a certain material refers to the restoration process of

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the material properties, meaning that the material has the capacity to partially revert the damage such as small cracks during pavement life [5]. It is well known that asphalt is capable of self-healing [6]. The problem is that healing at ambient temperature becomes a very slow process and therefore traffic flow would need to be interrupted during long periods to allow the pavement to get healed [7]. Healing asphalt mixtures is a complex phenomenon that depends on the activation energy of the binder, the capillary flow through the cracks, the self-diffusion of the molecules through the interface of the cracks, modification of the material and boundary conditions [8]. The external factors that influence the healing capacity are temperature, loading conditions, rest periods and humidity. Several researchers, analyzing these influencing factors, have proposed different methods, referable to three main approaches, to promote pavement healing: a) blend certain components into the binder in order to increase resistance and repair the bonding, b) use of enclosed/encapsulated chemical products to repair the broken bonds caused by micro-damage, c) heat the asphalt pavement in order to speed up healing and restore physical and mechanical properties [9–12]. Among the different heating approaches used to accelerate the healing process, the microwave technique, in which asphalt mixtures are exposed to an alternating electromagnetic field with a frequency in the order of Megahertz, has been recently investigated [13,14], also considering mixtures characterized by metallic fibers, such as steel wool [15], or by artificial aggregates, such as steel slags [16].

In parallel, recycling or reuse of pavement material, which results in considerable savings of material, money and energy, is one of the most effective rehabilitation alternatives available for asphalt pavements [17]. Hot and cold recycling can be done both in plants, batch or drum mix plants, and directly in place, hot in-place recycling (HIR), cold in-place recycling (CIR) and full-depth reclamation (FDR) [18–20]. Hot-in place recycling (heater scarification, repaving and remixing) was conceived in the past (mid-1970s) and was substantially abandoned at the end of the 1990s due to the economic and environmental imbalance compared to other more sustainable techniques which have been established, such as cold in-place recycling, fine milling, paving thin layers hot and cold [21]. Infrared or propane radiant heaters were historically used for softening and heating the road pavement surface, but these methods were accompanied by great energy loss, generation of gaseous hydrocarbon and particulate emission as well as frequent burning of the asphalt binder in the asphalt surface layer [22], also associated with odor nuisance [23,24]. More recently several patents have been issued and prototype equipment has demonstrated the feasibility of microwave heating of asphalt paving materials, with emphasis being placed on recycling [25]. Thus, hot-in place recycling supported by technological development is now finding a new potential interest in all those contexts where it is possible to organize efficient recycling trains designed to limit the energy consumption and to reduce gaseous hydrocarbon and particulate emissions released into the atmosphere [26,27].

In order to facilitate self-healing and hot in-place recycling of asphalt mixtures, the increase in temperatures as a result of the energy transmitted is certainly significant and is not independent from the thermal characteristics of the constituent materials [28]. The thermal history of an asphalt mixture, already from the initial mixing and placement processes, influences its mechanical performances and durability, since its reduction to thin film and high mixing temperatures (primary aging or short term-aging) and pavement in-service oxidation (secondary aging or long-term aging) accelerate the aging processes of asphalt binder, which tend to lose cohesion and ductility through a general stiffening [29]. Nevertheless, although some negative aging effects of asphalt binder on heated pavement had already been highlighted [30,31], the performances of microwave aged asphalt binders are still understudied.

This article aims, through an experimental laboratory approach, to directly compare two heating methods potentially used in flexible pavement rehabilitation, i.e. infrared (IR) and microwave (MW) radiations, for a preliminary assessment of the heating process characteristics (temperature distribution, energy consumption and duration) and on asphalt binder aging phenomenon.

2. Materials

The aggregate-asphalt binder blend used in the experimental analysis was determined after a preliminary mix design procedure. The aggregates selected for the HMA mixtures were porphyry coarse aggregate, silica sand and limestone filler, whereas the binder was an unmodified 50/70 penetration grade asphalt cement (Pen_{25} °C = 54 dmm; R&B = 51 °C). An AC 16 wearing course asphalt mixture, according to Spanish General Technical Specifications for Roads and Bridges (PG-3), was chosen as reference (Table 1).

Cylindrical specimens (Ø = 100 mm; h = 64 mm) were prepared with 4.6% of asphalt content by weight of the mixture at 165 °C and compacted using a Marshall hammer (EN 12697-30) [32] with 75 blows/side at 155 °C.

3. Experimental methodology

The testing program was divided in two main phases: thermal analysis of HMA samples during infrared and microwaves heating and evaluation of aging index of recovered asphalt cement after heating procedures.

The first step consisted in a thermographic analysis to measure the temperature and to produce the surface thermal map of the Marshall specimens during the heating process with infrared and microwaves radiations. A microwave oven (power output = 700 W; frequency = 2.45 GHz) and an infrared oven (power output = 1300 W) were used. The actual power energy consumed by both ovens was detected: the microwave oven consumed about 0.60 kWh and the infrared one about 0.95 kWh. Marshall specimens were diametrically cut and then the two halves were kept together during the heating session in the oven. Temperatures were measured with a time step of 120 s using a thermal imaging camera. The thermal maps of the samples were processed, using a thermographic analysis software to extract significant temperature parameters (maximum, minimum, average, variance coefficient). Specifically, the external surface temperature and the inner temperature of the central rectangular section (l = 100 mm; h = 62 mm) of each half specimen were registered (Fig. 1).

In parallel, the heating time necessary to reach predetermined temperatures by means of IR and MW radiations, was estimated. Two range temperatures were chosen in order to study the heating phenomenon, 120–130 °C and 150–160 °C. The first range could represent the temperature to rapidly heal the road pavement in-situ. Although temperatures of about 80 °C have been proven to be sufficient for activate the healing in laboratory scale, the difficulties imposed by traffic, dust and humidity inside the cracks, require an increasing in temperature for treatments in full scale

Table 1
Grain size distribution of AC 16 wearing course used in the investigation.

Sieve (mm) EN 933-1	22	16	8	4	2	0.5	0.25	0.063
% Passing	100	98	73	46.8	30.5	14.8	9.9	6.1