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Thermal Properties Evaluation of Pavement Mixture: A Review

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Abstract: Asphalt mixture is a temperature-sensitive substance. The mechanical properties and quality of the asphalt mixture are often affected by temperature. The elevated temperature is needed to dry the aggregate, coat it with asphalt binder, and achieve the desired workability. The aim of this study is to conduct a systematic literature review on the thermal properties evaluation of pavement mixture. The literature search used repositories database (ScienceDirect, Google Scholar, Scopus, Google) of 13 articles. Based on the review, there are various methods have been used to investigate the thermal properties of pavement mixture such as surface probe type, heat flux transducer and transient hot disc. The factors such as density and additive in asphalt binder can give effect on the thermal conductivity and specific heat capacity.

Keywords: Thermal Properties, Pavement Mixture, Hot Mix Asphalt

1. Introduction

Road surface is always exposed to ultra-violet and solar radiation. This radiation caused the pavement surface increased [1]. An increased pavement surface temperature will re-radiate and elevate the surrounding ambient temperature [2]. In pavement mixture, it contains aggregate and asphalt binder. Asphalt binder plays an important role in the performance of road. The viscoelastic nature of asphalt binder can vary with temperature and thus affect the mechanical properties of asphalt mixture [3]. In paving industry, hot mix asphalt (HMA) have been used for several decade and it is necessary to use elevated temperature to dry the aggregate, coat the aggregate with asphalt binder and achieved the desired workability [4]. Basically, thermal properties are fundamental criteria for analyzing the thermal flow of heat in a material and related to its conductivity of heat. The key components of the thermal properties such as heat capacity, thermal expansion, thermal stress, and thermal conductivity.

In HMA, thermal conductivity is described by several parameters such as thermal properties(α), thermal conductivity (κ), and the volumetric heat power (C) [5]. Thermal conductivity is to measure the rate at which heat is conducted through a particular material under specified conditions and property of a material that indicates its ability to conduct heat [6]. The problem that often occur which disturb

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the durability of HMA pavements are moisture, high traffic impact and temperature. This article reviews the method used to evaluate the thermal properties of pavement mixture.

2. Methodology

A thorough study of the literature review was carried out in a systematic manner. Various search engines or repositories are used including Science Direct, Engineering Village, Scopus and Google. Various journal articles and technical reports have been collected as shown in Figure 1. The searching quest resulted in 158 articles: 97 from Google scholars, 7 from Scopus, 36 from Science Direct and 18 from Springer Link. This covered the period from 2011 to February 2020, including subsequent tests, provided that the technology is still new and under review. Since scanning the titles and abstracting and screening the duplicates, 86 publications were removed, resulting in 72 articles. Finally, 13 publications applicable to the inclusion requirements were found after full text reading. In general, this article was read to create the full structure of the asphalt pavement and the study on the theme of heat transfer.

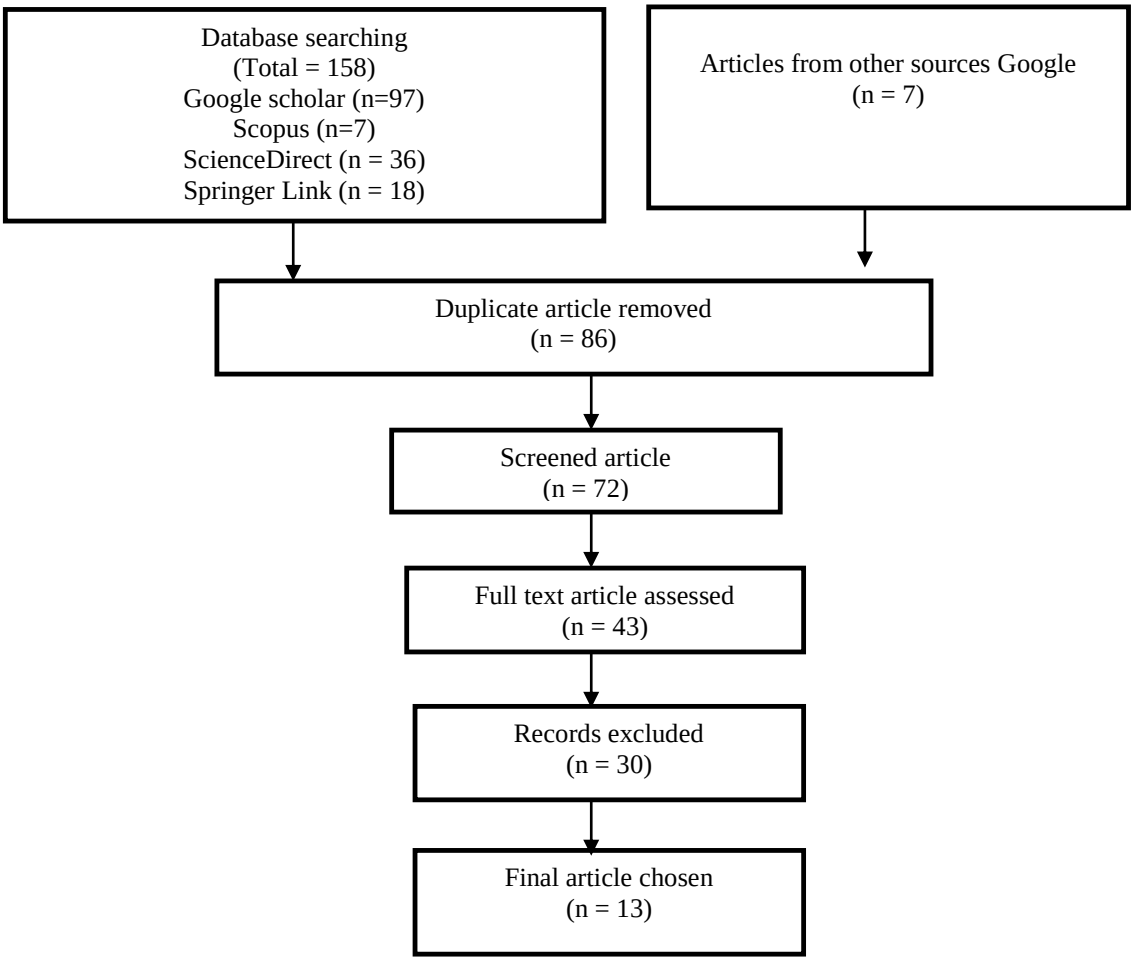

Figure 1: Flow of literature search

3. Discussion

This section describes the findings for thermal properties evaluation.

3.1 Testing Method of Thermal properties for Asphalt Mixture

Heat is a source of kinetic energy that transmit in three ways which are conduction, convection, and radiation [7] on site as shown in Figure 2. Heat transfer or also called thermal transfer would exist if there is a change in temperature. The study on thermal properties are important to understand the temperature distribution in asphalt mixture [8]. The testing method for thermal properties can be divided to two methods namely steady-state and transient state [9]. Steady state requires the specimen to reach stable test temperature and hence time consuming. Meanwhile, transient state can be conducted during the process of heating up or cooling down. Therefore, this method is fast and less time consuming.

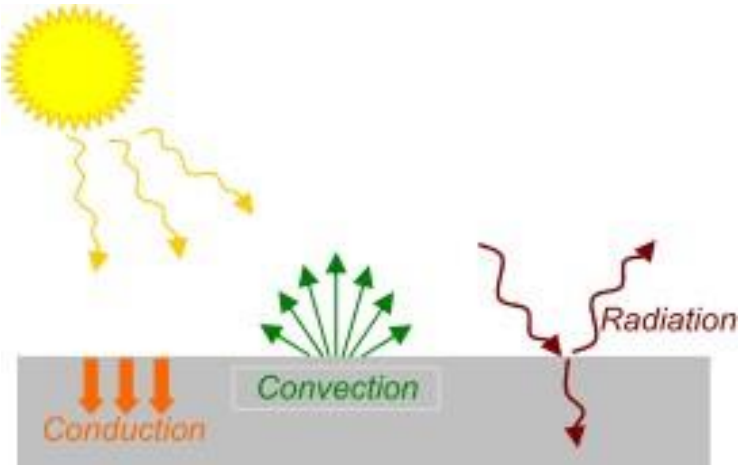

Figure 2: Heat transfer process in pavement layer [7]

In laboratory, the measurement of thermal properties of asphalt mixtures typically conducted under controlled heating sources. Table 1 presents the type of sample and measurement method for thermal properties evaluation. Hassn et al. [10] assessed the thermal properties of wet and dry condition for compacted slab under infrared lamps. Du et al. [11] used cylinder Marshall specimen under Iodine-tungsten lamps. According to Xu and Solaimanian [12], different shape of specimen has the influence on the thermal property measurement. The temperature of cylinder specimen was found to increase faster and sharp. Bai et al. [13] measured the thermal properties for asphalt mixture modified with conductive fillers.

Table 1: Method of thermal properties measurement

Author	Type of Sample	Method of measurement	Formula of Thermal Conductivity, K
Bai et al. 2015 [13]	Cylinder	Surface Probe type	$k = \frac{Q}{4\pi(T_2-T_1)} ln\frac{t_2}{t_1}$
Hassn et al. 2016 [10]	Slab	Geothermal Heat Flux Transduce	$K = \frac{Hf(t) \cdot H_s}{T_s(t) - T_b(t)}$
Slipets-Petkova & Zlateva, 2018 [7]	Cylinder	TCI thermal analyser – modified transient plane source	Not available
Du et al. 2020 [11]	Cylinder	Transient Hot disk method (measures by DRE-2C Thermal conductivity Tester)	Not available

Where k or K is thermal conductivity (W/mK), Q is heater power (W), T_1 and T_2 are initial and final measured temperature, t_1 and t_2 are initinial and final time (second), Hf(t) is heat flux through test slab at time t (W/m^2), H_s is the height of the test slab (m), $T_s(t)$ is the surface temperature (°C) and $T_b(t)$ is the bottom temperature (°C). The thermal properties of asphalt mixture were presented in term of thermal conductivity and specific heat capacity.

3.2 Thermal Conductivity

Thermal conductivity is defined as ratio of the heat flow to the temperature gradient [11]. Thermal conductivit (K) is generally expressed using the following formula [6]:

$$K = \frac{\Delta Q \,.\, X}{\Delta t \,.\, A \,.\, \Delta T} \qquad \text{Eq. 1}$$

Where K is the thermal conductivity of material, ΔQ is the change in heat energy between two points, X is the distance between two points, Δt is the change in time, Δ is the area of object in which heat flow is measured ΔT is the change in temperature that produced change in heat flow. K is used as an indication of heat transfer rate to or from a material. Unit of W/m.k refer to Watts per meter-Kelvin. 1-degree Kelvin is equal to 1 degree of Celsius [14]. Table 2 presents the value with different density of mixture. As the density of pavement mixture increased, K value also increases [5]. The higher value of K indicates the sample will transfer heat at higher rate.

Table 2: Thermal conductivity of different density pavement mixture

Hassn et al. 2016 [10]			Du et al. 2020 [11]		
Sample	**Density (kg/m3)**	**K (W/ m.K)**	**Sample**	**Density (kg/m3)**	**K (W/ m.K)**
Sample 1	2371.67	1.16	Control	2439	1.54
Sample 2	2186.75	0.96	Mixture 1	2398	1.48
Sample 3	2092.65	0.92	Mixture 2	2355	1.35
Sample 4	2004.70	0.90	Mixture 3	2312	1.24
Sample 5	1906.10	0.82	Mixture 4	2265	1.18

3.3 Specific Heat Capacity

Specific heat capacity is referring to quantity of heat required to increase the temperature of a unit volume of a material [5]. The unit for specific heat capacity is Joule/kg.°C or K. According to Bai et al. [13], the usage of conductive filler such as graphite has increased the thermal conductivity and reduced the specific heat of pavement mixture. the current development of modified asphalt binder which increased the thermal conductivity and decreased specific heat is beneficial for thermal performance of asphalt pavements [15].

4. Conclusion

The main purpose of this simple review is to collect the information about the thermal evaluation in pavement mixture. In order to understand the mechanism of thermal properties, the thermal evaluation was typically conducted in the laboratory. The cylinder sample typically used for the thermal testing. Two main parameters of thermal properties and specific heat capacity are depended on the density and additive in the asphalt binder. The increased thermal conductivity and decreasing specific heat capacity able to reduce the effect of temperature on the performance asphalt mixture.

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