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Microwave pre-heating of Asphalt recycling process

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Abstract, Normally roads are constructed of asphalt concrete. Roads, when used for a long time, usually get damaged. In the future, the road surfaces will be demolished and rebuilt to improve the quality from the old materials, in other words, recycling. In order to maintain the properties of asphalt, it must be preprocessed to allow it to retain its elastic deformation properties. In the past, asphalt was recycled by direct convection heating with fuels such as gas, oil, coal, etc., however, this method caused the asphalt to heat unevenly from the outside in, resulting in poor performance. Much more fuel is also required to heat the asphalt evenly, which leads to undesirable physical changes. This research is to study the use of microwave energy to allow for more evenly distributed heating of the asphalt. With it, the heating happens from the inside out, and decreases the unwanted physical property changes, which produces a higher quality end result, depending on the energy and time used to get these results. Initial revelation and results of the proposed process can be applied to the design and creation of an effective pre-heating device for asphalt road surface, as well as reducing energy consumption.

1. Introduction

The road has been a very important land transport method for mankind for a long time. Two types of materials used for road surface are the stable surface and the flexible surface with asphalt. Currently, asphalt used in Thailand is produced by oil distillation from petroleum production. In order to make asphalt useful for road, it must be heated at a temperature higher than the boiling point of water. This consumes fuel and there is a dangerous likelihood of resulting liquid asphalt. Usually, this type of asphalt is used to cover the road surface material. Materials for oil distillation have high cost and are not efficient at this present time, which causes us to search for a replacement fuel that conserves energy and is environmentally friendly.

Variation of the energy budget components of a dry asphalt surface over an annual cycle is discussed based on the analysis of data collected from a micrometeorological road station near Vienna, in Austria. Net radiation and ground heat flux are directly measured [1].

Moisture damage has been one of the major concerns for hot mix asphalt pavements. In the present study, efforts have been made to evaluate the moisture damage of a dense-graded surface mixture using simple performance test and superpave indirect tensile test. Coarse gravels at three different angularity levels (100, 50 and 0% fractured surface counts) used to produce mixtures with similar aggregate gradations. Asphalt binders with and without amine-based antistrip additive were used to make mixtures for laboratory moisture damage evaluations [2]. Water and thermal sensitivity of the open graded mixtures was prepared with asphalt rubber binder, one mixture containing lightweight aggregates (expanded clay) replacing a part of coarse fraction. Fatigue tests uses the Coaxial Shear Test apparatus to performed in both dry and wet conditions with and without temperature cycles [3].

The analytical temperature models based on the classical planar wall and long cylinder established to approximate the temperature distribution of asphalt concrete specimens with the geometry of a short cylinder or a beam [4].

Asphalt concrete, used for induction heating, was prepared by adding electrically conductive filler (steel fibers and steel wool) to the mixture. The main purpose of this paper is to examine the electrical conductivity and the indirect tensile strength of this conductive porous asphalt concrete and prove that it heated via induction heating [5].

For many years, Thailand's roads made from concrete asphalt. Road use, over an extended period of time, will accumulate damage and require maintenance. In these days, concrete asphalt is recycled by remixing with asphalt using a heating method with heat from burning fuel such as gas, oil, coal, etc. In this method, heat is conveyed from outside to inside of the material, which produces low-stability asphalt because the heating is not evenly distributed. Asphalt with high stability and quality requires much more energy consumption, consuming more fuel, and resulting in a higher cost.

Consequently, a research group has initiated a project "Application of microwave energy to heat asphalt for recycling" because microwave has the distinctive feature of heating from inside out. This enables heat to transfer to the asphalt evenly and does not change its physical quality. Asphalt heated from microwave energy has higher quality than by convection method and heat in concrete asphalt depends heavily on watts power, dielectric properties, and time. In this research, the authors design and manufacture equipment to bake asphalt surface for proper and effective recycling methods that reduce energy consumption and enhance environmental conservation.

Until now, the asphalt recycling process of microwave pre-heating has not been studied. The researcher realizes that microwave energy is an important alternative energy. This research aims to study microwave pre-heating in the asphalt-recycling process.

2. Experimental Setup

Figure 1 below shows sample asphalt from the damaged road with diameter of 90.5 mm and thickness of 50 mm (minimum thickness of asphalt from several sampled areas is 50 mm thick). Surfaces are smooth.

Figure 1. Test samples asphalt recycling.

The sample is baked by microwave. Power levels used for the baking are 700, 600, 500 and 400 watts. Baking duration for each power level is 5, 10, 15, 20 and 25 minutes, respectively. This research studies the optimal power and time to bake in order to liquify the surface.

The pre-heating system used in this project was a microwave oven with variable power output settings and a rated capacity of 850 watts at 2.45 GHz, outside dimensions (WxDxH) of 507x418x283 mm and cavity dimensions (WxDxH) of 350 x 320 x 200 mm. A schematic diagram microwave dryer is shown in figure 2.

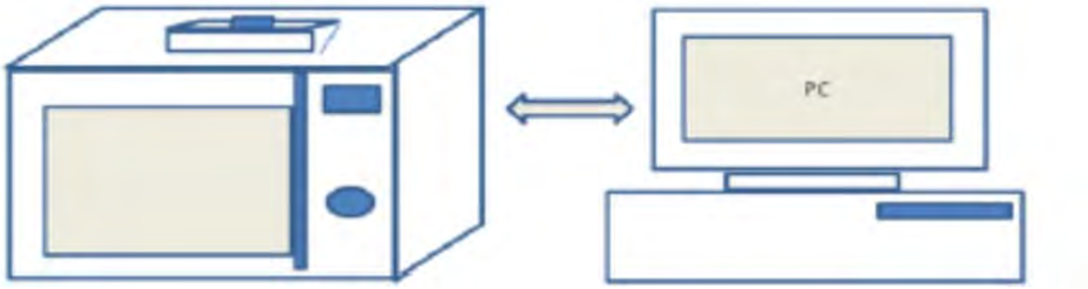

Figure 2. Microwave pre-heating setup [6]

The sample is baked by microwave and temperature is measured at 5 positions from the reference surface at power 800, 700, 600, 500 and 400 watts at 5, 10, 15, 20, 25 minutes. The sample figure and positions of measurement are shown in the figure 5.

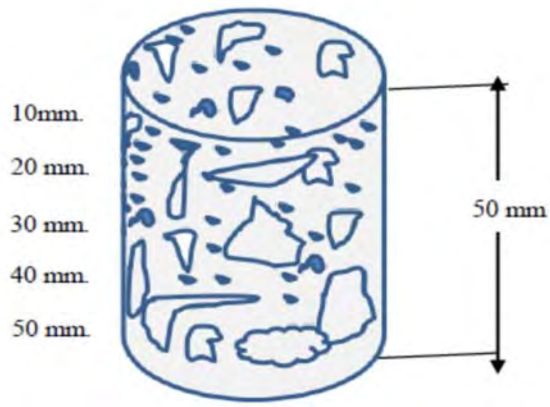

Figure. 3. Test temperature samples asphalt recycling.

3. Asphalt Properties

Asphalt is a complex hydrocarbon chemical compound and organic compound called bitumen that is a thick viscous to semi-solid liquid, semi-liquid is black or brown in colour that occurs naturally and is derived from refined petroleum [7].

Due to the viscous nature of asphalt at higher temperatures, it can be mixed with other substances that harden when cool, the following features and applications apply. Properties of binders: it is commonly mixed with rocks to make roads, sidewalks and parking lots. The ability to prevent seepage: water cannot flow through it, so it can be used for waterproofing the surface of reservoirs, dams, roofs, etc. [8].

Figure 4. Characteristics of the asphalt

The main material for construction is rock mixed or aggregate that mixed with binder. The favour binder is asphalt.

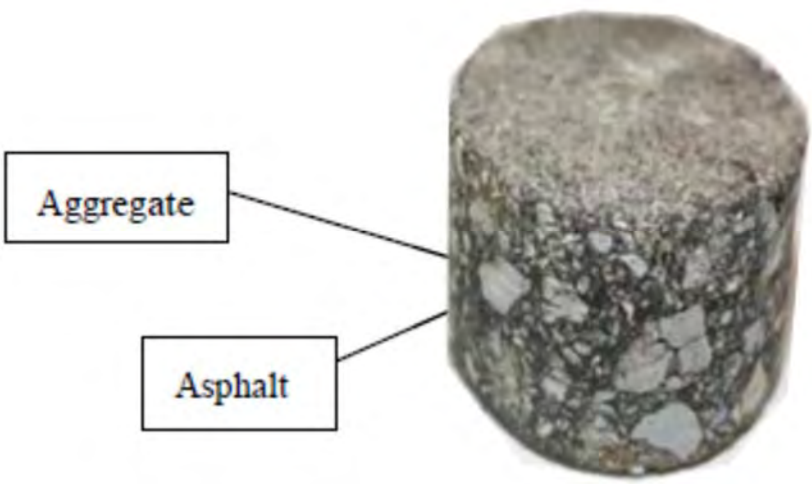

Figure 5. Composition of the asphalt

The mechanical property of asphalt: the sample of asphalt (50 mm thick) that is use in this research can support standard single axial load of 18,000 pounds [9].

4. Microwave Heat Generation

Microwave heating involves heat dissipation and microwaves propagation which causes the dipoles to vibrate and rotate. When the microwave energy emitted from a microwave oscillator (P_{in}) is irradiated inside the microwave applicator, the dielectric material which has a dielectric loss factor absorbs the energy and is heated up. Then the internal heat generation takes place. The basic equation for calculation of the density of microwave power absorbed by dielectric material (P_1) is given by [10]

$$P_1 = \omega \varepsilon_0 \varepsilon_r'' E^2 = 2\pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon_r' (tan\delta) E^2 \quad , \qquad (1)$$

where E is electromagnetic field intensity; f is microwave frequency; ω is angular velocity of microwave; ε_r' is relative dielectric constant; ε_0 is dielectric constant of air and $tan\,\delta$ is dielectric loss tangent coefficient.

From equation (1), P_1 is directly proportional to the frequency of the applied electric field and dielectric loss tangent coefficient and root-mean-square value of the electric field. It means that during an increasing of $tan\delta$ of specimen, energy absorption and heat generation are also increased. While $tan\delta$ is small, microwave will penetrate into specimen without heat generation. However, the temperature increase depends on other factors such as specific heat, size and characteristic of specimen.

When the material is heated unilaterally, it is found that as the dielectric constant and loss tangent coefficient vary, the penetration depth will be changed and the electric field within the dielectric material will be altered. The penetration depth is used to denote the depth at which the power density decreased to 37 % of its initial value at the surface [10].

$$D_p = \frac{1}{\frac{2\pi f}{\upsilon}\sqrt{\frac{\varepsilon_r'\left(\sqrt{1+\left(\frac{\varepsilon_r''}{\varepsilon_r'}\right)^2}-1\right)}{2}}} = \frac{1}{\frac{2\pi f}{\upsilon}\sqrt{\frac{\varepsilon_r'\left(\sqrt{1+(\tan\delta)^2}-1\right)}{2}}} \tag{2}$$

where D_P is penetration depth, ε_r'' is relative dielectric loss factor and υ is microwave speed. The penetration depth of the microwave power is calculated according to equation (2), which shows how it depends on the dielectric properties of the material. Note that products with huge dimensions and high loss factors may occasionally be overheated to a considerably thick layer on the outer layer. To prevent such phenomenon, the power density must be chosen so that enough time is provided for the essential heat exchange between boundary and core. If the thickness of the material is less than the penetration depth, only a fraction of the supplied energy will be absorbed. Furthermore, the dielectric properties of porous packed bed specimens typically show moderate lossiness depending on the actual composition of the material. With large amount of moisture content, it reveals a greater potential for absorbing microwaves. For typical of specimens, a decrease in the moisture content typically decreases ε_r'', accompanied by a slight increment in D_p.

In the analysis, energy P_2 is required to heat up the dielectric material W (g) placed in a microwave applicator. The initial temperature of material T_1, is raised to T_2. The energy P_2 can be estimated by the following calorific equation (3) [10].

$$P_2 = \frac{(4.18)W \cdot C_p \cdot \Delta T}{t} \tag{3}$$

where W is weight of the dielectric material, C_p is specific heat of the dielectric material, ΔT is the increment of temperature $(T_2 - T_1)$ and t is the heating time.

Assuming an ideal condition, all of the oscillated microwave energy **(** P_{in} **)** is absorbed into the dielectric material so that internal heat generation as shown in equation (1) takes place. In this case, the relation between P_{in} and P_2 is simply [10]

$$P_{in} = P_2 . \tag{4}$$

From a practical point of view, however, the transformation energy in applicator exists due to (1) the rate of microwave energy absorbed by means of the dielectric loss factor of the sample and (2) the energy loss in the microwave devices. Accordingly, by considering this transformation efficiency, the microwave oscillation output calculated by the following equations.

$$P_{in} = \frac{P_2}{\eta_m} \tag{5}$$

$$\eta_m = \frac{P_2}{P_{in}} \tag{6}$$

where

$$P_2 = \frac{Q \cdot S_p \cdot C_P \cdot \Delta T\left(4.18\right)}{\left(60\right)\eta_m \cdot 10^3} \tag{7}$$

where η_m is efficiency of microwave devices, Q is weight per meter of dielectric material (porous packed bed), S_p is the rate at which the dielectric material is put on the belt conveyer, C_P is specific heat of dielectric material and ΔT is heat-up range of $T_1 - T_0$.

5. Results and Discussion

The results of the experiment were compared to theoretical microwave heat generation. The results are related by the equation described in theoretical microwave heat generation. The end result is similar when the temperatures are similar.

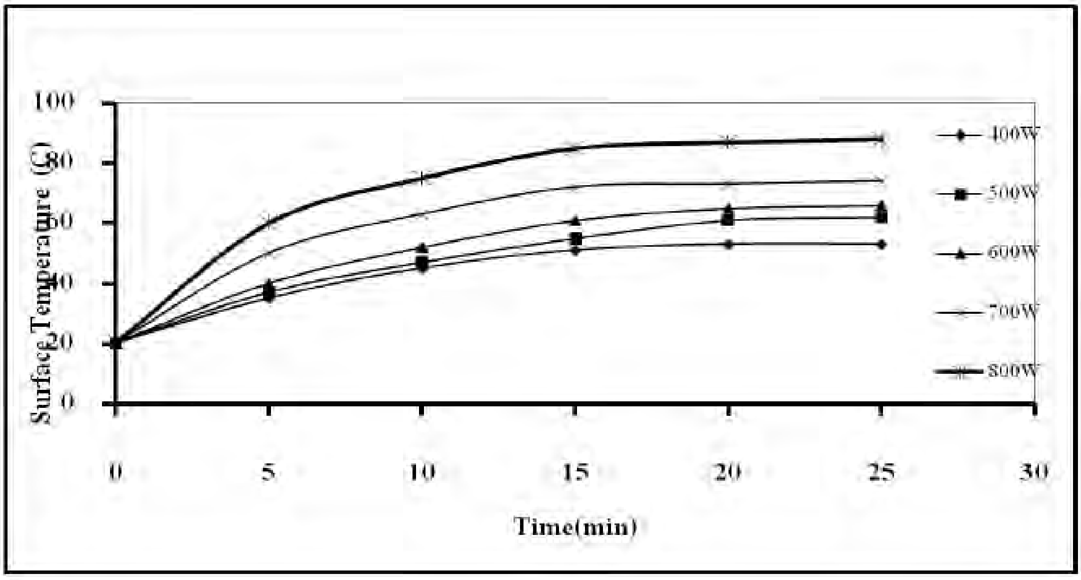

Figure 6. Surface temperature microwave pre-heating asphalt recycling.

Surface temperature microwave pre-heating asphalt recycling. Figure 6 is a graph showing the relationship between temperature and time [11, 12]. In experiments, the microwave power was set at 400, 500, 600, and 700 watts, with times of 5, 10, 15, 20, and 25 minutes. The asphalt pre-heated at different altitudes. The resulting curve is dispersed. The sample used is a mixture of aggregates used in the previous asphalt recycling test sample with maximum microwave power is set to 800 watts. This will heat the sample and achieve maximum depth in 15 minutes. The heat melts the asphalt surface. If use in a microwave and heated more for than 15 minutes per 800 watts will cause the asphalt to liquefy, which will not be suited for asphalt recycling because the physical and mechanical properties change.

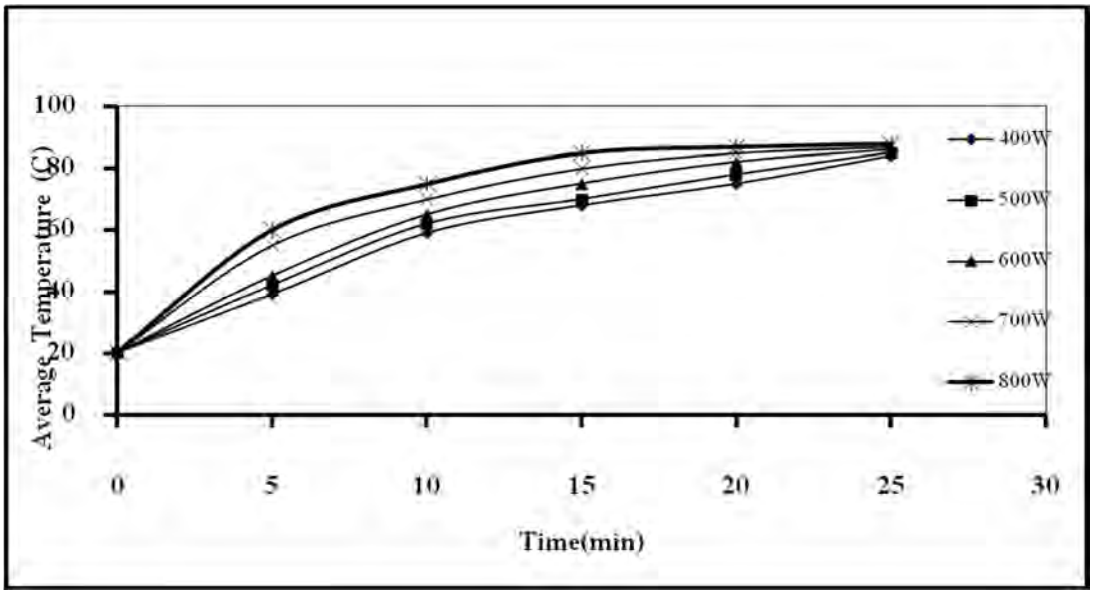

Figure 7. Average temperature microwave pre-heating asphalt recycling.

Figure 7 shows the average temperature during the experiment of pre-heating asphalt recycling. Microwave power levels are at 400, 500, 600, 700, and 800 watts. We can see that from the beginning to the end, the graph depicted relationship. According to the theory of microwave heat generation, microwave pre-heating occurs from the inside and spreads to the outside. With microwave power as well as temperature set to maximum, microwave pre-heating recycling asphalt is too time-consuming, even though the temperatures are similar.

Asphalt heated from microwave energy has higher quality than by convection baking; heat in concrete asphalt depends heavily on wattage, dielectric properties, and time. With microwave power set to a maximum of 800 watts, maximum penetration depth achieved. In maximum microwave power 800 watts, at 25 minutes, the heat will reach maximum depth but does not affect the depth too much.

6. Conclusions

In the process of heating asphalt by microwave at the difference of depth on the sample depends on power and time. The maximum power will generate high heat and deep heating as opposed to lower power because high power will generate more DP (the penetration value). At 25 minutes, high heat is generated which has a low effect of deep heating. The distribution of temperature on location of 20 mm is not homogeneous at the maximum power with location of depth that has maximum temperature because the difference is distributed dielectrically. The asphalt is melted at 800 watts for 3 minutes. At time over 3 minutes at 800 watts, it will melt more which is not suitable for recycling. The mechanical property of asphalt depends on power and time of heating process. In the future, the research will focus on property of dielectric and the physical properties of asphalt to analyze with math mode to study asphalt that has difference aggregate.

Acknowledgments

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