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STUDY THE EFFECT OF MICROWAVE HEATING ON PHYSICAL PROPERTIES OF ASPHALT

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Abstract: In this work, the effect of microwave on asphalt (heating rat, resistance to deformation and retain stability) was examined. Two different asphalt samples were used. The first, standard asphalt (A) and the second one with %2 of sulfur in bitumen (B) have been exposed to microwave. The measured temperature on the surface showed an increase up to 120 ºC in 5 minutes for sample A، while it reached to 145 ºC for sample in the second cycle of exposure to microwave in the same time. The increase rate in temperature for B samples was slightly lower. The presence of sulfur in asphalt reinforced the physical properties and the asphalt became more resistant to water and rutting for sample B after exposure to microwave radiation. Theoretically, the rise of temperature was found to be (0.64 ºC/minute) for one ton of asphalt needing microwave power energy of 1000 watt, but practically, some of this energy loss can be attributed to the conductivity and the penetration of the wave out of asphalt region. This study proved that the better incident angle reducing this loss by using the equation $ɵ=\sin^{-1}(x/(1/\ \alpha))$, and was found to be 28ºC and 37ºC for sample A and B respectively. The results showed the possibility of using microwave radiation in repairing the damaged roads asphalt with economic effective and green method.

Keyword: *Microwave, Asphalt, Penetration depth, Sulfur.*

دراسة تأثير الموجات المايكروية على تليين الاسفلت المستخدم في اكساء الطرق في العراق

الخلاصة: في هذا البحث تم اختبار تأثير الاشعة المايكروية على(معدل التسخين والمقاومه للتشويه والثباتية ضد الماء) للاسفلت. استخدمت مجموعتان مختلفتان من الاسفلت (احدها قياسية (A) والثانية مع أضافة الكبريت بنسبة 2% في القير(B)) وتم تعريضهما الى اشعاع المايكرويف. تم قياس درجة الحرارة على سطح العينات (A) اظهرت ارتفاع في درجات الحرارة لتصل الى 120مº خلال خمس دقائق، في حين وصلت الى 145 مº عند ما تم تعريضها مرة اخرى (بعد اعادة كبسها وتشكيلها مرة ثانية) لأشعة المايكرويف ولنفس الفترة الزمنية ، بينما كان معدل الصعود في درجات الحرارة اقل بقليل للعينات التي تحتوي على الكبريت (B) اذ اظهرت نتائج الفحوص الفيزياوية ان وجود الكبريت قد عزز من مقاومة الاسفلت لنفاذية الماء وكذلك صموده ضد التخدد ويظهر ذلك جليا بعد تعرضها لأشعة المايكرويف . نظريا، وجد ان لرفع درجة حرارة مقدارها 0.64 درجة مئوية / دقيقة ولكتلة 1 طن من الاسفلت يتطلب طاقة من أشعة المايكرويف مقدارها 1000 واط ،لكن عمليا، بعض من هذه الطاقة تفقد بواسطة التوصيل الحراري بالمحيط او بواسطة اختراق أشعة المايكرويف الى خارج منطقة الاسفلت المراد تسخينه، لذلك تم حساب افضل زاوية سقوط للاشعة المايكروية لأقل فقدان بواسطة المعادلة ($ɵ=\sin^{-1}(x/(1/\ \alpha)$) وكانت قيمها 28º و 37º لكل من العينة A و B على التوالي. لقد اظهرت النتائج بأمكانية استخدام اشعة المايكرويف في اصلاح اسفلت الطرق التالفة بطريقة اقتصادية وفعالة وصديقة للبيئة.

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1. Introduction

Asphalt is one of the materials using for road pavement. Asphalt is uses in bituminous (flexible pavement) construction. Recently, the need to asphalt recycling is becoming increasingly very important [1]. In the United States, Malaysia and other developed countries, asphalt is used in more than 94% of road surfaces, only 6% are rigid pavements and in many countries, only asphalt roads are in service and there are no rigid pavements in service. On average, 6% of asphalt actually is used for the construction of flexible pavement in the world's highways. To meet the requirement of high volume of asphalt pavement construction, the requirement for asphalt is increasing at 2.3% per year and it is reach 114 million tons in 2009 [2].

The goal of "microwave" recycling is to consistently produce 100% recycled mixes. As transfer method with the indirect heat, however, stone gradation control considerations can limit the reclaimed asphalt pavement (RAP) content to below 100%. The (RAP) may have more fine aggregate sizes than the final mix desired, so forcing RAP percentages down with the introduction of small amounts of coarse virgin rock. Conventional convective heat transfer is used to heat and dry the RAP to an elevated temperature and a microwave heating is employed in the final stages to raise the material to the desired paving temperature [3].

Los Angeles, California, has the largest locally street paving operation in the world. Every year, its Bureau of Street Maintenance repaves and repairs about, 150 miles of deteriorated roadways with 800,000 tons of hot mixed asphalt (HMA). The Bureau employs 4 fulltime milling crews that remove up to 250,000 tons of old road asphalt yearly. Los Angeles has been manufacturing hot mixed asphalt (HMA) with a 15% RAP composition for years. In 1987, the city began seeking methods to recycle more RAP due to an impending landfill shortage. During that year, the city learned of a process that uses direct microwave heating to produce high-quality HMA using little of virgin aggregate. This process was developed by CYCLEAN, Inc. of Austin, Texas [4,5].

The addition of sulfur effect on the physicochemical properties of bitumen and its role to prolonging the service life or work time of asphalt has been investigated in many researches, obviously [6]. Proved that the reaction between sulfur and bitumen depends on temperature and sulfur concentration in bitumen. At melting point (160 °C), sulfur has octet ring form and at higher temperature it forms polymer and gets the form of 2-radical chain. These radicals could react with bitumen in two ways: forming carbon - sulfur bond or absorbing hydrogen and consequently dehydrogenization occurs. The probability of all these reactions depends on temperature [7]. These reactions lead to bind bitumen components, and therefore increase plasticity and reduce cracking of bitumen at low temperature. On the other hand, the increase in sulfur content leads to reduce softness and increase water permeability and resistance to solubility [8].

The present work; study the effect of the microwave radiation on heating asphalt, and observing the effect of this radiation on the physical properties of asphalt with the addition of sulfur.

1.1. Microwave Heating

The theory of microwave heating has been extensively discussed widely. There are two mechanisms of microwave heating: dipole rotation and ion polarization. The first happens when polar materials are exposed to electromagnetic field; it will polled toward the external field and the resistance of molecules in this materials against polling process will appears as heat. The value of this heat depends on loss factor of dielectric (imaginary part). In contrast, the second occurs in samples containing ions such as electrolytes. In the presence of an electromagnetic field, the positive ions perform electrophoretic migration toward the negative; they collide with other ions and molecules so that heat is generated. When dielectric loss occurs, the absorbed microwave energy can be dissipated as heat [Rana et al.,2014]. The amount of power absorbed and the rate of heat generation depend on the dielectric properties of the materials, the intensity and frequency of the applied microwave radiation [9]. The microwave energy is assumed to enter the road way from the normal (z) direction or at an appropriate angle, as transverse electromagnetic wave (for heating of patch compound for pothole repair can be modeled as a one dimensional problem), one can set up a heat balance on a per unit time and unit volume as:

$$\text{TES} = \text{microwave energy adsorbed} + \text{net heat input by conduction} \qquad (1)$$

Where: (TES) is the thermal energy stored and can be determined by

$$\text{TES} = \rho CP\ (\partial T/\partial t) \qquad (2)$$

Where ρ is the material density (Kg/m^3), C_P is the heat capacity (J/Kg.°C), T is the temperature °C, and t is the time in seconds.
The thermal energy generated by absorption of microwave is given by

$$\text{Microwave energy absorbed} = 2\alpha P_{in} \qquad (3)$$

Where α is the microwave absorption coefficient (or attenuation constant) of the material (m^{-1}), P_{in} is the power energy of microwave (W/m^2). The reciprocal of absorption coefficient (1/ α), is known as the penetration depth (the penetration depth is the depth when the 86.5% of incident energy is absorbed). In one dimension, the net heat input by conduction is given by:

$$\rho C_P\ (\partial T/\partial t) = \kappa\ (\partial^2 T/\partial z^2) \qquad (4)$$

Where κ is the thermal conductivity (W/m/ °C) and z is distance of heat diffusion (m) , then the equation (1) can be written:

$$C_P\ (\partial T/\partial t) = 2\alpha P_{in} + \kappa\ (\partial^2 T/\partial z^2) \qquad (5)\ [10]$$

When a microwave penetrates a dielectric, its amplitude will decrease as the power flux density falls. This reduction is due to power dissipation within the material caused by the dielectric loss factor. If assumed that there is no wave reflected on the surface so, the rate of field intensity decay is exponential with increasing distance from the materials surface and the penetration depth of wave (D_P) is given by Equation below

$$D_P=\lambda^{o}(\varepsilon_r)^{0.5}/2\pi\varepsilon'' \quad (6)$$

Where λ^o is the wavelength (m) and ε_r , ε'' are the real and imaginary part of dielectric constant respectively. The importance of the dielectric constant ε_r is evident in the penetration depth. When increasing the ratio of ε_r, the rate of decay of the power density falls correspondingly to the increasing penetration depth. Likewise, larger loss factor values lead to good microwave energy absorbing in material and reduce the penetration depth and results in non-uniform temperature distribution from the center to the surface of the workload [11].

2. Experimental Work

2.1. Devices and Instruments

2.1.1. Microwave oven, (model: CLATron, Germany) was used (with input power 1150 watt and output power 700 watt and frequency 2.4 GHz) to heat the samples.

2.1.2. Spy heat thermometer model (AR350), manufactured by Smart sensor company, was used to measure temperature of asphalt samples.

2.2. *Materials*

2.2.1. Aggregates mixture of asphalt test specimens as shown in Table1, with bitumen ratio 4.1% for samples A. as for samples B, 2% of bitumen was replaced with sulfur.

2.2.2. Bitumen

The physical properties of bitumen which used in this research (grid 40-50) from Al-Nasiriyah liquidator are illustrated in Table 2, according to specification of highway and bridges directorate (Iraq).

2.2.3. Sulfur with density (1.97 g/cm^3), Al- Mishraq factory-Iraq.

Table 1: Aggregate mixture of asphalt test specimens.

Condition of sieve	25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	300 µm	200 µm	Bitumen
Passing from the sieve%	100	95	80	66	50	35	13	6.3	4.1%

Table 2: The physical properties of uses bitumen.

Tests	Penetration at 25° C (100g,5sec)	Flash point °C	Loss on heating %	Ductility	Softening point. °C	Solubility in Organic Solvents %min.	Viscosity, (60° C), Poise.
Results	40	305	0.15	>100	54	99.87	4220

2.3. *Test Procedure*

The samples of asphalt on the form of disc with average diameter 102 mm and average thickness 68.4 mm (ρ=2350 Kg/m3 and heat capacity = 925 J/Kg.ºC) have been exposed to microwave radiation and the temperature change with time of samples surfaces were recorded by using spy heat thermometer. The samples were broken (become fragile) after the exposure to microwave when heated to specific temperatures. So, the samples were re-formed again as discs by compression and considered as PAB. The exposure test to microwave was repeated again as before and the temperature of the samples surface was recorded for second cycle of exposure.

3. Results and Discussion

The positive effect of microwave on asphalt samples has been observed obviously in Fig.1. The increase of temperature was up to 120 ºC for samples A and 145 ºC for its RAP during 5 minutes. This heating can be attributed to the contribution of dielectric loss for different materials in asphalt samples. The slight increase of temperature for RAP A can be explained as a result of breaking which happened for aggregates of samples A after heating. This behavior is consistent with the increase in the surface of aggregates after the broken which led to increase the thermal diffusion (($\partial^2 T/\partial z^2$), (see equation (4)) from inside the samples to its surface.

To understand the contribution ratio of heating for all components of materials (compound of aggregates with sand alone, and bitumen alone) in asphalt, these materials have been exposed to microwave separately. The rising in temperature for one Kg of these materials is showed in Fig. 2. It appeared that the aggregate with sand has contributed to increase the temperature in asphalt samples more than the bitumen. However, the change in thermal (conductivity) after added the sulfur showed inverse behavior of samples B and its RAP as compared with A and its RAP, Fig.3. This behavior can be attributed to the thermal conductivity of the addition Sulfur (0.205 W/m/ºC)) which is higher than the bitumen ((0.17 W/m/ºC) [12], in addition to that, the presence of sulfur helps to formation the bitumen molecules cross linking by vulcanization process due to sulfur bridges which connects the carbons of backbone chains in bitumen.

After exposure to microwave radiation, the heat change of (RAP) B showed lower drop in temperature values as a result of de-vulcanization which occurred with the help of microwave [13].

Although the physical testing properties indicated slight deviation in deformation values of RAP for A samples which it is attributed to the loss of bitumen elasticity by heat effect, but it is still in the range of technical specifications of roads in Iraq. In the contrary, for RAP of B samples, the effect of microwave has been given obvious improvement as shown in Fig. (4). This rise in the value of resistance to deformation can be explained by increase of adhesion between the bitumen and aggregates as impact of the sulfur presence as well as the elasticity improvement of the bitumen after the de-vulcanization work happened by micro wave energy [6].

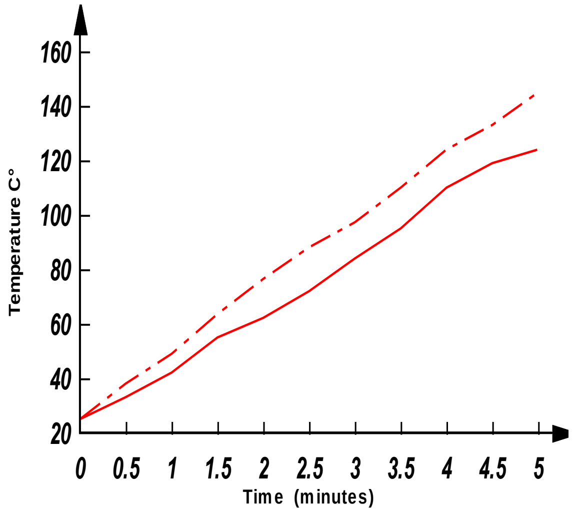

Fig 1 The increasing of temperature with time of exposure by microwave, a) continuous line samples A, b) dashed line for RAP A.

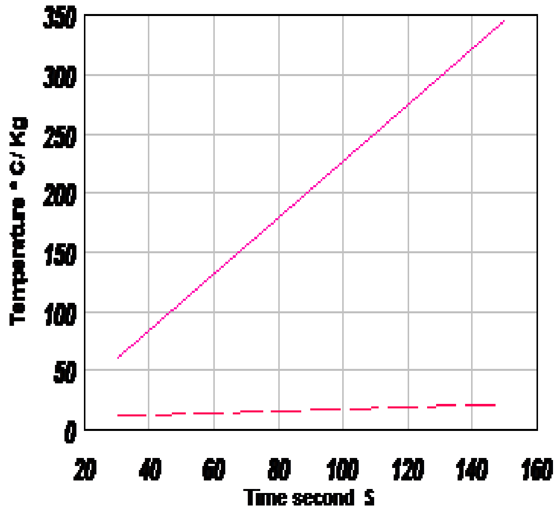

Fig 2 Temperature change by microw-ave of a) Aggregate with Sand, continu-ous line. B) Bitumen, dashed line.

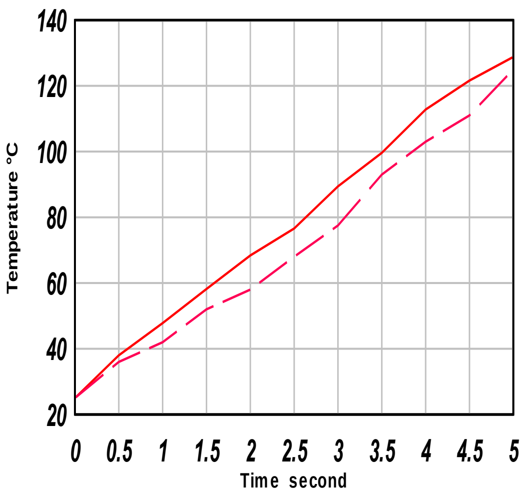

Fig 3 The increasing of temperature with time exposure of microwave radiation a) dashed line for samples B; b) continues line for (RAP) B samples.

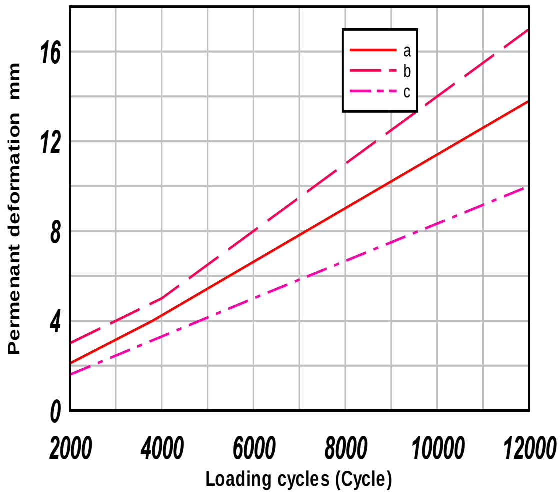

Fig 4 Hamburg Wheel – Track Testing, a) reference asphalt, b) RAP A, c) RAP B.

From Table (3), it can be observed that the retained stability (in the conditions, 49 °C and 4 hours) for PAB A and PAB B samples are significantly higher than the non treated samples which indicate a decrease of pores happened after exposure to microwave radiation, and improvements the water resistance of samples after treatment.

Table 3: The retained force for different samples.

sample	Sample without treatment	PAB A	PAB B
% retained	71.2	73.4	79.6

The calculation of energy transformation from microwave radiation to the asphalt roads, should take into consideration the loss of energy in two ways, the first by thermal conduction between the asphalt and its surrounding environment which there is no possibility of controlling it. The second way is by penetration of microwave beam far from the asphalt region. To avoid more energy loss, values of penetration were found for two samples of asphalt A and B Fig. (5), which showed the effect of sulfur presence in asphalt led to decrease the penetration of microwave beam.

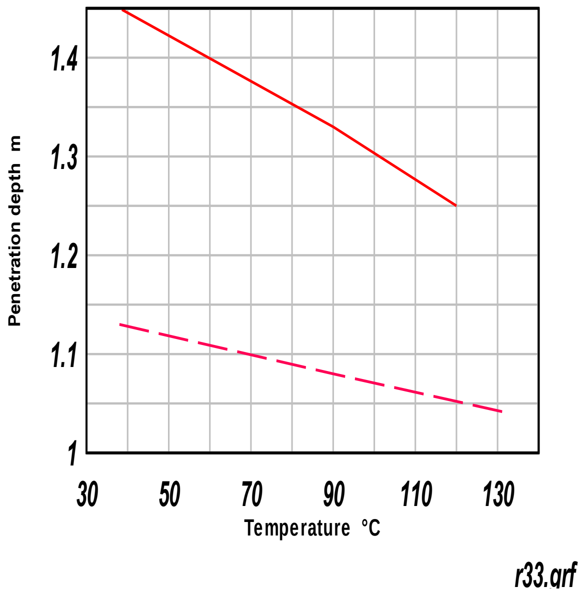

Fig (5): penetration depth of microwave in, a) sample A, continues line, b) sample B dashed line

To have the best angle (ɵ) which prevents the radiation that does not penetrate more than the asphalt region, it is possible by assuming the thickness of asphalt equal to x, and the penetration of microwave value equal to (1/α) then the incident angle of the radiation (the angle between the asphalt surface and radiation direction) will be equal to $\theta=\sin^{-1}(x/(1/\alpha))$. This angle was calculated for sample A and B, and it was 28º and 37º respectively.

Due to the low heat diffusion of asphalt, it was observed that there were different temperature values between the surface and the core of samples. Sometime this difference reach to 30ºC (the heating of asphalt sample by microwave could be considered as system of spot heat of aggregates isolated by bitumen thin film). So the calculations of transferred energy which depend on surface temperature do not give real results of power transformation to asphalt. For this reason, the calculations should depend on ideal case (assuming all the microwave energy transforms to the asphalt without loss of energy).The calculations by using equation (2) showed that the temperature increases of one ton of the asphalt by microwave power radiation (1kw) for one minute equal to (0.64 ºC).

4. Conclusions

1. The heating of asphalt by microwave radiation is a successful way to rise the temperature and reuse or repair of the damaged asphalt in situ. The recycled asphalt in this method ensure the preservation of its physical properties and it will reduces the amount of required energy to reuse asphalt compared with to the old ways.
2. The measured temperature on the surface showed an increase up to 120 ºC during 5 minutes for standard sample, while it reached to 145 ºC for sample in second cycle of exposure to microwave, but for samples with sulfur the increasing was slightly lower.
3. The low heat diffusion of asphalt causes a measurement error of temperature between the surface and the inside of the asphalt, this difference in measurement of temperature may reach to 30ºC by using IR spy heat thermometer and it worth mentioning, there is no ability to use the other techniques (because the damage which is happened of devices measurement by microwave), so should take in account that the real temperature is always higher than the measuring temperature on the asphalt surface.
4. The presence of sulfur will improve the physical properties of asphalt such as resistance to deformity and water resister, but this improvement was more obvious after the exposure the asphalt to microwave as a result of decreasing the contribution of the sulfur bonding with the bitumen molecules as well as enhancement of adhesion of bitumen with aggregates in presence of microwave radiation.

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