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Performance of Half Warm Rolled Asphalt mixtures

Abbas Al-Hdabi [a,*], Hassan Al Nageim [b]

[a] Civil Engineering Department, Faculty of Engineering, Kufa University, Iraq
[b] School of Built Environment, Liverpool John Moores University, Peter Jost Centre, Byrom Street, Liverpool L3 3AF, UK

HIGHLIGHTS

- Microwave heating is used to produce a novel Half-Warm Rolled Asphalt by means of a pre-compacting microwave heating method.
- The optimum microwave conditioning time was indicated in terms of stiffness modulus, air voids content and temperature.
- The mechanical properties of HWRA is promising due to high early stiffness modulus and long fatigue life.

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ABSTRACT

One of the major problems that have plagued cold Bitumen Emulsion Mixtures (BEMs) since their introduction is high air voids. Therefore, this research will focus on this property and the attempts that have been applied to decrease the air voids of the produced new mixtures will be explained.

In this connection, microwave heating has several advantages in comparison with the conventional heating method such as: it is volumetric heating, which represents an energy-saving point, and promotes rapid curing, which might enhance productivity. Therefore, a novel Half-Warm Rolled Asphalt (HWRA) has been produced by means of a pre-compaction microwave heating method.

Consequently, Cold Rolled Asphalt (CRA) mixtures containing Ternary Blended Filler (TBF-2) have been mixed and then microwave heating, with 2450 MHz frequency and 300 W power, was applied in different durations in the pre-compaction method. The optimum microwave conditioning time was indicated in terms of stiffness modulus, air voids content and temperature which was 3 min microwave conditioning was chosen as the air voids decreased from 10.1% to 7.3%, the stiffness modulus decreased slightly and within an acceptable range and, finally, the temperature was in the moderate range (69 °C).

The mechanical properties of HWRA have been investigated in terms of stiffness modulus, creep performance, fatigue life and fatigue fracture while water sensitivity and Long Term Oven Aging (LTOA) were conducted to investigate its durability. Generally, the performance in terms of mechanical properties and durability is promising due to high early stiffness modulus, long fatigue life and high Stiffness Modulus Ratio (SMR) in comparison with the control CRA and conventional hot asphalt mixtures.

1. Introduction

The major problems that have plagued cold Bituminous Emulsion Mixtures BEMs) since their introduction are their slow curing rate, low early strength and high air voids. Several research such as [1] stated that the first and second problems have been improved significantly but the latter, i.e. high air voids content, is still very high in comparison with conventional hot bituminous mixtures. Therefore, this research will focus on this property and the attempts that have been applied to decrease the air voids of the produced new mixtures will be explained.

1.1. Influence of air voids content on asphalts' performance

Many studies have been conducted to investigate the influence of air void content on the properties of hot asphalts. Generally, the stiffness modulus of hot asphalts is considerably affected by any increase in air void content [19]. Also, road engineers limit the air voids contents of hot mixtures to be within the BS EN specifications. Their value also must be not <3% to prevent permanent deformation at early life. Suparma [16] reported that permeable bituminous mixtures are more exposed to stripping, therefore

* Corresponding author.
E-mail addresses: abbas.alhadabi@uokufa.edu.iq (A. Al-Hdabi), H.K.Alnageim@ljmu.ac.uk (H.A. Nageim).

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the mixtures with higher air voids are expected to have a higher risk of stripping.

Several studies have been conducted to investigate such relationships between air voids and stiffness modulus for cold BEMs such as Dash [4], Lanre [11] and Ibrahim [7]. These studies were focused on the main parameters which affect the air voids contents in these mixtures such as aggregate gradation, type and level of compactive effort and curing mechanism and time.

Ibrahim [7] studied the influence of different emulsion mixture variables on material compactibility. Three types of compaction method – Marshall, vibration and gyratory – were examined for use in compaction of these mixtures. In terms of compaction method, the researcher prepared a set of samples which were compacted to approximately similar bulk density using the Marshall Hammer, vibrating compaction and gyratory compaction and then tested to indicate stiffness modulus at different curing times. The researcher concluded that the compaction method affected the stiffness modulus of cold BEMs significantly as the vibratory compaction showed much higher stiffness modulus than the other compaction methods after being cured due to a higher coalescence of bitumen droplets onto aggregate particles. On the other hand, the researcher stated that stiffness modulus increased considerably with increasing of compaction effort as the air voids decreased and in turn the interaction between the binder and the aggregate particles increased.

Generally, the target air voids content range for cold BEMs is between 5 and 10%, as reported by Thanaya [17] who used gyratory compaction at laboratory specimens, therefore the researcher recommended a heavy compaction effort for these mixtures to achieve the said target. Further, he stated that consideration in the selection of an appropriate compaction method is required to achieve both the volumetric and the engineering characteristics. Accordingly, the researcher stated that increasing the compaction effort can easily lead to reducing the air voids of cold BEMs to comply with a preselected target value. In more detail, he reported that, in order to achieve the target air voids, the cold BEMs need to be compacted using 240 gyros, which was designated in his study as extra heavy compaction. Compaction at 80 gyros represented medium compaction effort which is considered to correspond to 50 blows utilising the Marshall Hammer, whereas heavy compaction is carried out at 120 gyros, corresponding to 75 blows.

Also, the Asphalt Institute and Asphalt Emulsion Manufacturers Association [3] stated that drying or aeration preceding compaction may be required especially for gradations containing considerable fine materials. This process leads to the production of cold BEM with lower air voids, higher density, and higher strength in comparison with cold mixtures compacted at the same mixing water content.

Lanre [11] reported that mixing and compaction temperature is very significant to produce cold BEMs with low air voids as the researcher observed that cold BEMs prepared at 32 °C gave better results, lower air voids content and higher stiffness in comparison with those mixtures prepared at 20 °C.

Dash [4] conducted a comparative study between two types of cold BEM with different gradations, namely dense bituminous concrete and stone mastic bituminous mixtures. One of the parameters studied was to investigate the effect of compaction effort and type which in turn consisted of Marshall Hammer and Gyratory compaction. the researcher found that the latter type of compaction was highly active in decreasing the air voids content despite not indicating much influence on the Marshall Stability.

1.2. Overview of microwave heating

The development of microwave technology began at the time of developing high definition radar during World War II. The potential of microwaves to heat substances was accidentally discovered when conducting random experimentations utilising a microwave generator. Since that time, there has been huge progress in microwave heating in industrial applications and the consumer market as well. The rapid growth of microwave technology in the 1970s was due to its versatility over conventional heating more than its affordability. However, some socio-technical events were then observed questioning the safety of exposure to microwaves [15].

Kobusheshe [10] stated the main differences between microwave heating and conventional heating which are shown in Table 1.

The microwave oven has been commonly used in most kitchens in the last 25 years. As shown in Table 1, energy savings, cooking time and volumetric heating are the basic advantages over the conventional heating system. Consequently, Thostenson and Chou [18] reported that microwave heating for processing materials can possibly offer similar advantages, i.e. decreased processing time and energy saving. Meredith [12] stated that time of microwave heating can often be decreased to 1% in comparison with the conventional heating with <10% energy consume variation in the workload.

Microwaves are a kind of electromagnetic wave between infrared radiation and radio waves, as shown in Fig. 1, with wavelengths between 0.001 and 1 m and frequencies between 900 and 2450 MHz [12]. In terms of efficiency, Meredith [12] reported that the overall efficiency of a well-designed microwave heating system is very high, 80% at 2450 MHz, while conventional heating methods operate at around 30% efficiency.

Microwaves can penetrate materials and deposit energy throughout the volume of the material as microwave energy is delivered directly to materials through molecular interaction with the electromagnetic field, as reported by Thostenson and Chou [18]. Thus, there is a possibility to achieve fast and uniform heating of whole materials by using microwave energy.

Microwave technology can process mineral materials and carbon-related material, as reported by previous studies [6,13]. Also, Menedez et al. [13] stated that using microwave heating for the pre-heating process in the bituminous material mixing process prevents the oxidation of bitumen during this process in addition to the previous advantages. Furthermore, Jeon et al. [8] stated that there is a possibility that the microwaves can break up the larger molecules in the bitumen and generate light oil fractions.

Jenkins [9] investigated the possibility of preparing bituminous mixtures at temperatures higher than ambient temperature but below 100 °C, and termed this mix as a Half-Warm Foamed mix (HWF). the researcher stated many benefits that can be achieved when adopting such mixtures, namely improved tensile strength, particle coating and durability, in comparison with BSM-foam, which is produced at ambient temperature. The main HWF advantages in comparison to Warm Mix Asphalt (WMA) and Hot Mix Asphalt (HMA) are its shear strength and the potential energy-saving element, as the extra energy required by the latent heat of water vapour when exceeding its boiling point could be avoided.

Table 1
Summary of the differences between microwave and conventional convection heating.

	Microwave heating	Conventional convection heating
Source	Energy transfer	Heat transfer via conduction
Start up	Immediate	Related to heating chamber
Rate	Rapid heating possible	Related to thermal diffusivity
Uniformity	Volumetric and selective heating	Temperature gradient from surface
Energy loss	Waveguide to reduce loss	Loss due to radiation externally