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Critical Analysis on Adopting Cold Asphalt Emulsion Mixtures in Hot Climatic Areas

Abbas Al-Hdabi

Abstract— Asphalt mixture produced at ambient temperature by using asphalt emulsion is known as Cold Asphalt Emulsion Mixture (CAEM). Also, it can be produced by incorporating various recycling road materials. Some cementitious materials such as cement and several waste or/and by product materials can be incorporated especially if those materials have cementitious or pozolanic properties to enhance the strength of CAEMs.

The energy revolution for offering sustainable energy supply and utilize in terms of economically and environmentally is interested evident for governments and industry. Cement is the main material for constructing the society's buildings and infrastructures. Meanwhile, 5% of global CO2 emission is related to cement industry. Therefore, replacing of cement with one of the other sustainable materials is one of the main objectives of the climate change mitigation strategies around the world.

On the other hand, the effect of temperature by means of preparation, curing and testing temperatures is one of the main issues which strongly influence the performance of the produced mixtures. Therefore, this study is trying to introduce a comparison study between cold and warm-hot areas to indicate the possibility of adopting applying such as these mixtures in developing countries which suffer a warm-hot climatic, south and middle of Iraq is an example.

The mechanical properties were assessed by conducting Indirect Tensile Stiffness Modulus (ITSM) as a respected indicator of the performance of CAEM at different preparation, curing and testing temperatures. The warm-hot temperatures will contribute the evaporation of the trapped water and overcome the poor early strength of CAEM. Also, despite ITSM decreases due to temperature increase, the performance of CAEMs is much better than the control hot mixtures because of its less temperature sensitivity.

Index Terms— hot asphalt, cold asphalt, cement, asphalt emulsion, weather, stiffness modulus, temperature change.

1 INTRODUCTION

IN Iraq, road network majority is constructed with asphalt concrete pavement in which HAM is utilized mainly as a paving mix for many years. Several limitations associated with these HAMs such as excessive emission of greenhouse gases from HAM plant, expenses of installation of HAM plant is high and the cost of small sectors of rural roads is extremely fewer in comparison with suburban roads, close of HAM plants throughout rainy period and laying of those mixtures is difficult in rural and suburban areas due to the long hauling distances [1].

Most of Iraqi highway and road network is exposed to a multitude of severe environmental aspects, principally the substantial axle load applied on these roads, the extraordinary traffic and extreme high temperature. Excessive failures at an early period of the pavement life can be revealed in these roads. Several steps in the improvement of the existing performance during the pavement life are recommended such as modification of the mix design, adopting new technology of pavement construction, etc…

Abbas Al-Hdabi is currently a Lecturer, Department of civil engineering, Faculty of engineering, university of Kufa, Al-Najaf, Iraq, abbas.alhadabi@uokufa.edu.iq and alhudabi73@yahoo.com

As Iraqi road network such as different areas around the world needs to be developed, asphalt paving mix such as warm or cold mix should be attempted. These mix design are introduced to lay on pavement to overcome the problems which are connected with HAM.

Warm Asphalt Mix (WAM) can be used to produce asphalt mixtures. This group of techniques are utilised to produce asphalt mixtures at mixing and compacting temperatures lower than the conventional HAM. The idea behind producing WAM is to reduce bitumen viscosity either by incorporating of chemical or organic substances or by pressing cool water into the pre-heated asphalt cement under controlled conditions of pressure and temperature (foamed bitumen). Evotherm, Asphaltan-B, Asphamin, Sasobit and WAM-Foam are examples of the available WAM technologies [2].

Using one of the WAMs instead of traditional HAM has several benefits, one of which is the reduction in mixing and compaction temperatures. [3] reported other advantages including: decreased fuel and energy consumption, decreased emissions and odours from plants, decreased smoke, enhanced working conditions at the site, thus improving the quality of the work as well as the workers' productivity, longer hauling distances and extending the paving season.

While, Cold Asphalt Emulsion Mixtures (CAEMs) are manufactured at ambient temperatures utilising asphalt emulsion as binder. However, some procedures can use warm emulsion up to around 60 °C. Although there is no need to dry the aggregate, the water content must be controlled because it strongly affects the performance of the produced mixtures. The main role of the pre-mixing water is to prevent premature breakage of the emulsion. Then the bitumen emulsion is gradually added to the pre-wetted aggregate and mixed until maximum aggregate coating is achieved by the binder [4].

CAEMs are still limited to road pavements that accommodate low to medium traffic due to their intrinsic problems, especially insufficient early strength and long curing time required. [5] reported that CAEMs can be utilised in all pavement layers designed for low to medium traffic loads. However, for heavily trafficked roads, at least a 40 mm hot asphalt layer is needed to overlay the CAEM layer.

CAEMs can be applied in different ways such as hand application and laying equipment's i.e. pavers and girders. Different compaction techniques are utilised for CAEMs depending on the manufacturing company. However, [6] stated that steel rolling then a heavy roller with pneumatic tyred and finally with a steel roller is the preferred technique. Over rolling at the mixing stage can lead to excessive emulsion breakage which can seal the surface, preventing curing and cracking; therefore, a degree of caution must be exercised by operators.

Previously, CAEMs were produced with open graded or semi-dense graded mixtures to ensure better airflow, thus improving the curing process due to the high air voids in these mixtures. In line with improvement of emulsion technology and preparation techniques, currently CAEMs can be produced even with dense or gap gradation mixtures [5].

Suitable aggregate gradation, asphalt emulsion and pre-mixing water are required for the CAEM mix design. [7] stated that the emulsion's breaking mechanism and the compactability of the mixtures control the performance of the produced mixtures in the field. Asphalt emulsion's breaking during curing covers the total evaporation of water followed by an effective distribution of the mixture's constituents and coating of the aggregate by asphalt emulsions.

Paving mixtures produced with CAEM or WAM need to be attempted in Iraq due to the development of road network continuously. These mix are started to lay on pavement to overcome the problems which are related to HAM. Therefore, CAEM must be tried in hot climatic areas (middle and southern of Iraq) as well as in areas which have high rainfall and difficult terrain (north regions of Iraq).

2 Effect of Temperature Change on Performance of CAEMs

In accordance to the previous studies, the main factors which are affecting the performance of CAEMs are curing temperature, curing time, preparation temperature and environment i.e. humidity and ambient temperature when the mixture will be in service. Therefore, this paper will focus on the influence of preparation, curing and testing temperatures on the mechanical properties of these mixtures.

Serfass et al. (2004) studied the effect of curing on the mechanical properties of CAEMs. A grave emulsion with maximum size of 14 mm has been prepared from 4% of 70/100 base asphalt and semi crushed alluvial aggregate with different compaction and curing conditions to investigate the compressive strength of these mixtures. They concluded that cold emulsified asphalt must be cured for 14 days at 20% relative humidity and 35°C to achieve a comparable strength with hot mixtures.

[8] inspected the influence of curing conditions, temperature and moisture on the performance of Cement Bitumen Treated Mixtures (CBTM). The recycled material was collected the Italian A14 motorway during the Full Depth Reclamation (FDR) operations of this motorway. All mixtures have been prepared with 3% C60 B asphalt emulsion and a II/B-LL 32.5 R cement type. The influence of temperature and curing on stiffness modulus and repeated load resistance have been assessed by conducting repeated indirect tensile tests.

Their study investigated mixtures' ITSM on three sets of samples cured at constant temperatures for different periods representing the typical seasonal conditions in Italy i.e. 40 °C for 28 days (summer temperature), 20 °C for 63 days (spring and autumn temperature) and 5 °C for 56 days (winter temperature), the results are shown in Fig. 1. It is clearly shown from this figure that the maximum ITSM was reached after 7, 21 and 42 days for the 40 °C, 20 °C and 5 °C cured mixtures, respectively. They concluded that higher curing temperatures leads to higher rates of stiffness increase and higher maximum values.

Then, they studied temperature effect on cold CBTM' stiffness as they conducted ITSM test at different temperatures i.e. 5, 20, 40 and 50 °C. The results, as shown in Fig. 2, confirmed the thermos-dependence of these mixtures, showing that stiffness modulus decreased with temperature increased.

A different behavior has been observed for HAM in comparison with CBTM by means of temperature sensitivity as it displayed a significant higher thermal sensitivity in comparison with CBTM. Accordingly, CBTM suffers, during hot seasons, less distortion and rutting in comparison with HAM.

The possibility of preparing asphalt mixtures at temperatures which are higher than 20C has been studied by several researchers such as [9] who termed to the produced mixtures as Half-Warm Foamed mix (HWF). Many advantages have been reported when adopting these mixtures in comparison with control mixtures namely improved tensile strength, durability and particle coating.

3 CAEMs' Mechanical Properties at Different Curing, Preparation and Testing Temperatures

The main concerns when adopting CAEMs, as reported by the previous researches are the long curing time, which is required to trapped water to be evaporated, to reach the optimum performance and the early days' poor strength due to the existence of water. The above two concerns are strongly related to the environment i.e. ambient temperature which play the main role within preparation of these mixtures, curing, and performance (by means of mechanical properties and durability) of these mixtures. The Chevron Research Company directed field and laboratory researches to evaluate CAEM' performance in California. They reported that these mixtures required between 2– 24 months to achieve the maximum curing in the field depending on the weather conditions and mixture's ingredients [10].

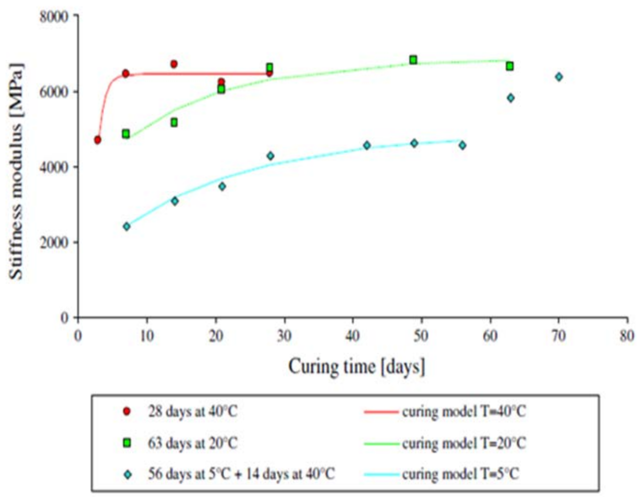

Fig. 1. Evolution of ITSM as a function of curing temperature and time [8].

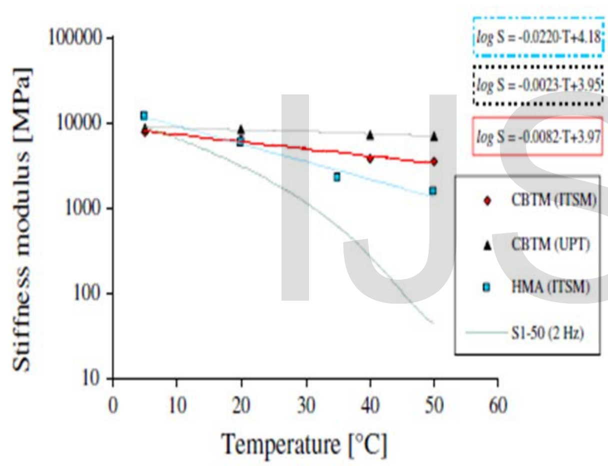

Fig. 2. Comparison between CBTM and HMA temperature sensitivity [8].

Accordingly, this research article will investigate the influence of preparation temperature, curing temperature and testing temperature on the properties of CAEMs. Also, this research will investigate the possibility of adopting these mixtures to be used as binder and/or surface course in hot climatic areas, such as middle and south of Iraq, in accordance to the laboratory test and literature review which is related to this topic.

All CAEMs in this research have been prepared in accordance with the Asphalt Institute procedure [4] to produce different Dense Graded Cold Asphalt Mixtures (DGCAM). The ITSM was used as an indicator to investigate the properties of the whole CAEMs. The aggregates i.e. fine and coarse utilised in this research were crushed granite, while a cementitious material was used as mineral filler. K3-60, Cationic slow setting asphalt emulsion, has been incorporated to produce all CAEMs. A close graded with 10 mm maximum size gradation, suitable for surface course, was adopted to produce the DGCAMs as per BS EN 4987 [11]. 3 %, by mass of aggregate, of the pre-wetting water were incorporated to the coarse, fine aggregate and filler substances and mixed thoroughly for 1 min. After that, 12 % of asphalt emulsion, by mass of aggregate, was added gradually and the mixing was continued for 2 min. Impact compactor i.e. Marshall Hammer with 50 blows to the two faces of the 100 mm diameter specimen was applied as the general compacting process.

ITSM was used to investigate the mechanical properties of the CAEM and HAMs, Fig. 3 shows the loading device with loading and deformation strips and specimen in place. The normal curing procedure for DGCAM was i) before extruded the samples from the molds, they have been left in the mold for 24 h at 20 ºC, then ii) left the samples at 20 ºC until conducting the test at the designated age on a flat surface. As per EN 12697- 26:2012 [12], the normal test temperature was at 20 ºC.

The ITSM results of the prepared CAEM at different curing time i.e. 1, 3, 7, 14 and 28 days and 20 °C curing, preparation and testing temperature is shown in Fig. 4. Generally, all the produced CAEMs have a stiffness modulus values greater than the control HAM (14mm close graded HAMs). Also, the stiffness increment is very high at early days (less than 7 days) in comparison with the other.

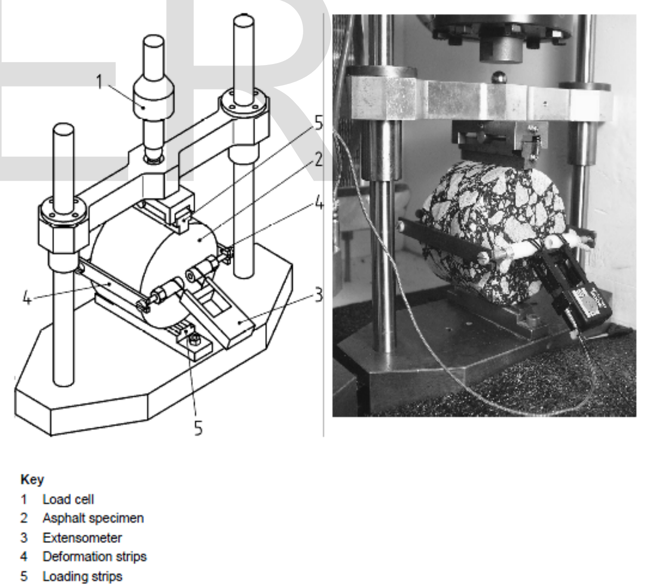

Fig. 3. The loading device with loading and deformation strips and specimen in place [12].

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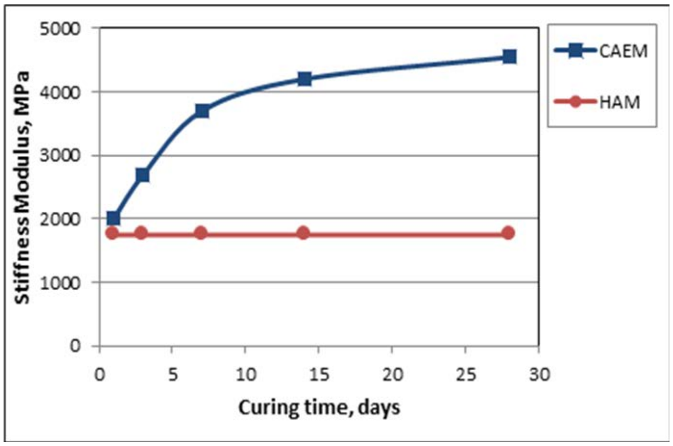

Fig. 4. Effect of curing time on ITSM results for CAEM mixtures

To investigate the influence of curing temperature on the performance of CAEMs, another set of samples were prepared as detailed above and cured at 40 °C then tested in accordance with EN 12697- 26: 2012 at 20 °C, Fig. 5. As presented in this figure, there is a huge difference between ITSM results for the samples cured at 40 °C in comparison with those cured at 20 °C. The percentage of increase in these values is more than 80% for the CAEM cured at 40 °C for 1 day in comparison with the other mixtures. From this point of view, it can be concluded that the areas with higher temperature is more appropriate to the evolution of the strength of CAEM. Higher temperatures will help these mixtures to evaporate the trapped water that is generated from the pre-wetting water content and the water which is released after asphalt emulsion breaking. Also, high temperature i.e. 40 °C will activate the hydration process of the cementitious filler (which has been used in this study) with water.

To evaluate the CAEMs' performance at various testing temperatures, ITSM was tested at 5, 20 and 40 °C at 28 days and the results are presented in Fig. 6. It is clearly shown that CAEM is less sensitive to the temperature change in comparison with the HAM as the temperature sensitivity is normally characterized by the gradient of the curve, as the relationship between ITSM vs temperature has been drawn in a semi-logarithmic plane. Mixture is more susceptible to the temperature which has higher rate of change. Accordingly, it is estimated that CAEMs will perform better than traditional HAM at high and low temperatures. Also, the percentage of stiffness modulus decrease is almost 45% when the testing temperature increased from 20 °C to 40 °C but the interesting point here is the stiffness modulus value (2460MPa) still achieve the required stiffness modulus value i.e. 2000MPa.

Lastly, the influence of preparation of CAEM at high temperature on the performance of these mixtures has been studied. Another set of samples has been prepared (mixed and compacted) at 40 °C and cured and tested at 20 °C at different curing time i.e. 1, 3, 7, 14 and 28 days, Fig. 7. As shown in the figure below, there is a little decrease in stiffness modulus after 1 day for CAEM prepared at 40 °C when compared with the control mixtures, less than 8%. As, presented in other researchers such as [6] [13] and [14], the early strength of CAEM is the main concern when adopting this kind of mixtures, therefore and due to the little decrease in the ITSM values, it can be stated that the effect of preparation of CAEM at higher temperature i.e. not more than 40 °C has a little influence on CAEMs' performance.

From the previous laboratory results it can be concluded that the performance of CAEM is strongly related to the environment temperature.

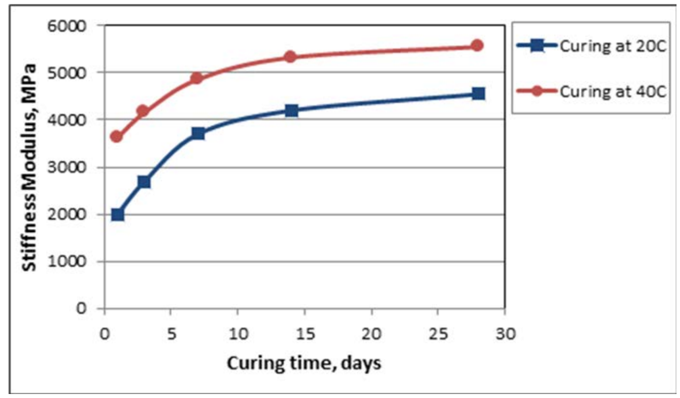

Fig. 5. ITSM results of CAEM at 20 ºC and 40 ºC curing temperature with different curing time.

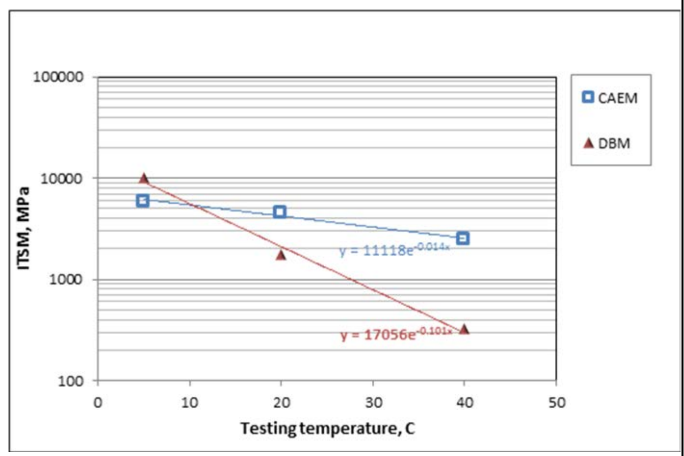

Fig. 6. Temperature susceptibility of CAEM in comparison with DBM.

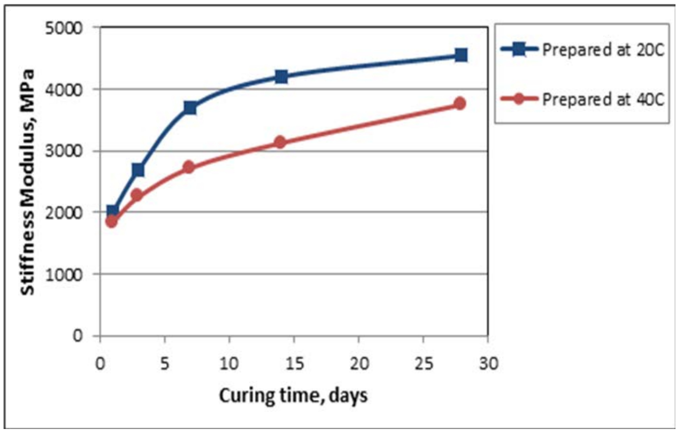

Fig. 7. Effect of preparing temperature on ITSM of CAEM mixtures.

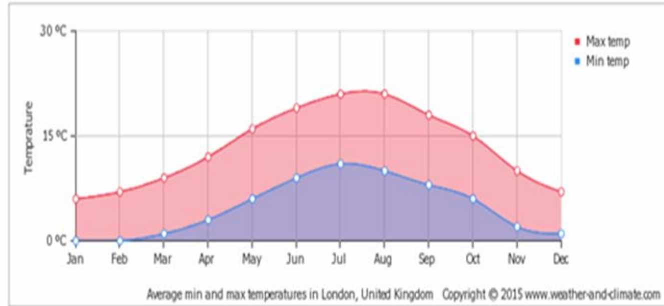

Fig. 8. Average min and max temperatures in London, UK [16].

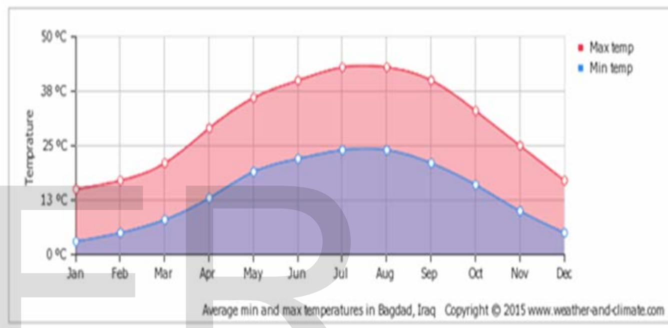

Fig. 9. Average min and max temperatures in Baghdad, Iraq [17].

4 Critical analysis on adopting CAEMs for hot areas Citations

There is very limited studies that are investigating the performance of CAEM in developing countries which have high environment temperatures in comparison with European countries. Therefore this study tried to investigate the ability of introduce these mixture as an economic alternative to the hot mixtures. Fig. 8 and 9 presents the average min and max temperatures in London, UK and Baghdad, Iraq, respectively as an examples of the above described countries. While, Fig. 10 illustrates the average monthly temperatures in these areas.

Generally there is a big difference in temperatures between London and Baghdad as it looks like the weather in the later is very hot, it is one of the hottest places, especially in summer as the maximum temperature is more than 35 °C between May and October.

Several studies, such as [15], reported that the strength of cold asphalt emulsion mixtures principally be nfluenced by the evaporation process of the trapped water in the mix, hence warmer climate is more appropriate for CAEMs application. These high temperatures will contribute the evaporation of the trapped water which is incorporated in CAEMs and overcome the disadvantages of early poor strength. On the other hand, despite the stiffness modulus decreased due to temperature increase, the performance of these mixture will be much better than the conventional hot mixtures because of its less temperature sensitivity as discussed in Fig. 6. Furthermore, there is little concern of high temperature i.e. more than 35 °C by means of mixtures preparation.

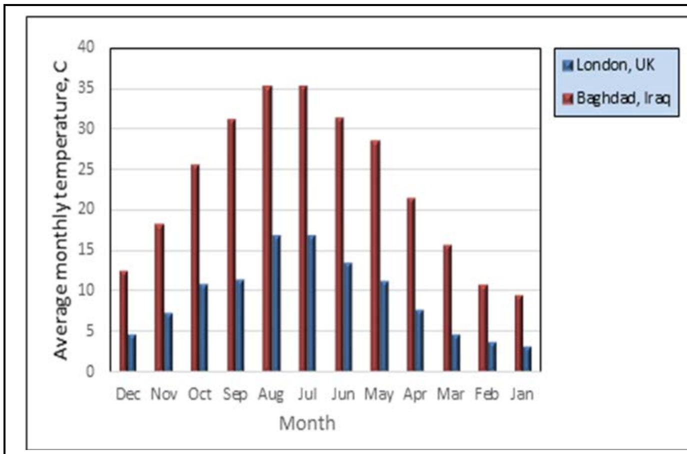

Fig. 10. Average monthly temperature in London, UK and Baghdad, Iraq, ºC.

5 Conclusions

CAEMs have been produced by incorporating of cementitious material as mineral filler and conventional K3-60 asphalt emulsion (cationic slow setting) with different preparation, curing and testing temperatures to investigate the performance of these mixtures. The mechanical properties were assessed by conducting ITSM as a respected indicator of the performance of CAEM. Below are the main conclusions from this research:

1. The ITSM value is increased significantly with curing temperature of CAEMs increase. The percentages of ITSM increase is more than 80% for CAEMs cured at 40 °C in comparison with 20 °C cured samples.
2. There is an unremarkable decrease of ITSM results at early days for the mixtures prepared at higher temperature.
3. The ITSM results decreased with temperature increase. But, it can be noted that CAEM with cementitious filler perform better than conventional HAMs as its less temperature sensitivity in comparison with these mixtures.
4. In accordance to the weather investigation and comparison study between hot and cold areas, it is strongly recommended that CAEM is very suitable to the hot developing countries as it more economic and satisfactory in addition to the sustainability issue.

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