Mechanical Properties of Ordinary Portland Cement Modified Cold Bitumen Emulsion Mixture

Hayder Kamil Shanbara, Felicite Ruddock, William Atherton, Nassier A. Nassir

Abstract**—**Cold bitumen emulsion mixture (CBEM) offers a series benefits as compared with hot mix asphalt (HMA); these include environmental factors, energy saving, the resolution of logistical challenges that can characterise hot mix, and the potential to reserve funds. However, this mixture has some problems similar to any bituminous mixtures as it has low early strength, long curing time that needed to obtain the maximum performance, high air voids and considered inferior to HMA. Thus, CBEM has been used in limited applications such as lightly trafficked roads, footways and reinstatements. This laboratory study describes the development of CBEM using ordinary Portland cement (OPC) instead of the traditional mineral filler. Stiffness modulus, moisture damage and temperature sensitivity tests were used to evaluate the mechanical properties of the produced mixtures. The study concluded that there is a substantial improvement in the mechanical properties and moisture damage resistance of CBEMs containing OPC. Also, the produced cement modified CBEM shows a considerable lower thermal sensitivity than the conventional CBEM.

Keywords**—**Cold bitumen emulsion mixture, moisture damage, OPC, stiffness modulus, temperature sensitivity.

I. Introduction

ASPHALT mixture is a composite material that generally consists of bitumen as a binder, aggregate and voids. It has commonly been used as a material for constructing flexible road pavements because of the good adhesion that exists between binder and aggregates [1]. Recently, there is an increased awareness of using cold mixtures in pavement industry instead of using hot bitumen [2]. CBEM is one of the common types of cold mix asphalt (CMA) and defined as an alternative to the conventional hot mixtures, as no heating is required in its production. It is an emulsified bitumen mixture that can be manufactured at ambient temperatures and used in roadway construction. Accordingly, CBEM is considered as environmentally friendly, energy efficient, cost-effective and sustainable option. Although CBEM provides both economic and environmental advantages in terms of removing the need for heating huge amounts of aggregates and bitumen, it is rarely used due to its weak early strength, long curing time, high air voids and poor mechanical properties [3].

Several investigations have been carried out to enhance the mechanical properties of the CBEM using virgin natural materials. Several aspects to improve the performance of such mixture have been performed such as incorporating various types of materials and applying different preparation techniques. Reference [4] focused on the influence of curing procedures and compaction types, and concluded that the increasing of curing time develops the indirect tensile stiffness modulus. Increasing of compaction efforts leads to improve the degree of emulsion combination when using granite aggregate with 20 mm aggregate maximum size [5]. Reference [6] reported that the air voids of CBEMs could be within the specification limits by adopting heavy compaction (120 revolution, 240 kPa, 2° angle of gyration) rather than medium compaction (80 revolution, 240 kPa, 2° angle of gyration). The aimed air voids content of the compacted CBEMs (between 5 and 10%) could be obtained by applying 240 gyrations, which are categorised as extra heavy compaction. Additionally, a heavy compaction application is crucial to approve breaking of the emulsion and ensure that mixtures strengthen properly [7]. The excessive amount of liquids in CBEMs reduces the compaction effect and prevents mixtures from obtaining their acceptable air voids leading to decrease stiffness and strength properties. Reference [8] carried out a laboratory investigation to study the impact of polymers modified emulsions on the mechanical properties of emulsified bitumen macadam. Close graded surface course and dense graded binder course were used as aggregate grading with a cationic emulsion containing 65% base bitumen of 100-pen grade. It was concluded that Ethylene Vinyl Acetate (EVA) and Styrene-Butadiene-Styrene (SBS) polymers have positive effects on modification of the bitumen emulsion in terms of enhancing the stiffness and permanent deformation of CBEMs. In addition, fatigue resistance of 4% SBS and 6% EVA modified CBEMs were developed about 45 and 35 times, respectively, in comparison with the fatigue resistance of unmodified CBEMs. In further

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research, polyvinyl acetate was added to a rapid-setting emulsified bitumen to improve the compressive strength of CMA [9]. Recently, [10] used a specially developed polymer modified emulsifier in AC-13 asphalt mixture. It was concluded that in terms of moisture susceptibility, high temperature and resistance to low-temperature crack, the mixture met performance specification requirements in addition to an improvement in rutting resistance performance.

II. Cement Development

Additives can play a main role in governing the engineering properties of bituminous mixtures in terms of stiffness, permanent deformation resistance, fracture resistance and moisture sensitivity. Some of these additives are used as a filler replacement in the mix such as cement and lime. Cement can be technically defined as a material that if mixed with other non-cohesive particles give a hard mass. It is a fine powder such as Portland, slag, pozzolanic and high alumina which generate very strong and durable binding materials because of the hydration processes [11]. The use of cement in bituminous mixtures is not a new idea. Reference [12] carried out one of the first studies that used cement into emulsion-treated mixtures. It was concluded from this study that using cement as an activator in the bitumen emulsion mixtures can accelerate the rate of development of the resilient modulus due to the accelerated rate of curing of such mixtures. This means that Ca^{2+} ions from cement neutralises the anionic emulsifier allowing emulsion droplets to coalesce and adhere to the aggregates. This helps in breaking the emulsion quickly and absorbing water from the mixture thus decreasing curing times [13]. Reference [14] found that adding 1% OPC as a modifier to the cold asphalt mixtures increases the Marshall Stability by 300% compared with untreated mixtures. Reference [15] stated that the OPC modified emulsion mixtures decreases the layer thickness about 50% as a result stability improvements (200%-300%). Reference [16] reported that the cement-asphalt emulsion composite has a longer fatigue life, less temperature susceptibility and higher toughness. Reference [5] evaluated the effects of incorporating OPC into the bitumen emulsion mixtures. Cement type affects the rate of increase in strength of CBEMs [6]. Reference [6] testified that Rapid Setting Cement (RSC) gives a better rate of increase in strength in comparison to the OPC. The stiffness of the modified CBEMs with RSC was about 2000-2500 MPa after a few weeks of curing, whilst the unmodified mixtures needed 16 weeks to achieve same stiffness values. This is because the RSC behaves as an active filler in CBEMs causing an increase in the pH. References [17] and [18] carried out laboratory studies to evaluate the addition of 0-6% OPC as a filler replacement to the emulsified asphalt. The results showed significant developments in the mechanical properties of these modified mixtures with higher percentage of OPC. Reference [19] found that the cement in the cement asphalt emulsion mixtures can improve the micro hardness of the interface. Reference [20] investigated various cement percentages on the mechanical properties of CMAs that cured at different environmental humidity levels (35, 70 and 90% RH). It was proved that incorporation of cement into bituminous mixtures results changes in the pH of the emulsion leading to break it quickly. Reference [21] studied the effect of replacing all the conventional mineral filler with OPC in order to develop a new cement treated CBEM made with gap grading. The results indicated that gap-graded, cold rolled asphalt mixtures gained significant enhancements in mechanical properties, resistance to water damage and temperature susceptibility. Reference [22] investigated the use of rapid hardening cement to accelerate the development of mechanical properties of cement bitumen emulsion mixtures and obtained better understanding of the role of cement in such mixtures. After one day curing of mixtures with calcium sulfoaluminate and calcium aluminate cements, the mechanical properties were comparable to those mixed by using Portland cement after one week of curing.

III. Materials and Methods

A. Materials

1) Aggregate

CBEM performance mainly depends on the size, type and gradation of the aggregated used. According to the European Committee for Standardisation [23], asphalt concrete, close graded surface coarse with 14 mm aggregate maximum size was selected for producing CBEMs. This aggregate is granite crushed which is hard rock with a granular structure and considered the most common type in the world. The grading is as shown in Fig. 1 along with the specification for a 14 mm close graded surface course.

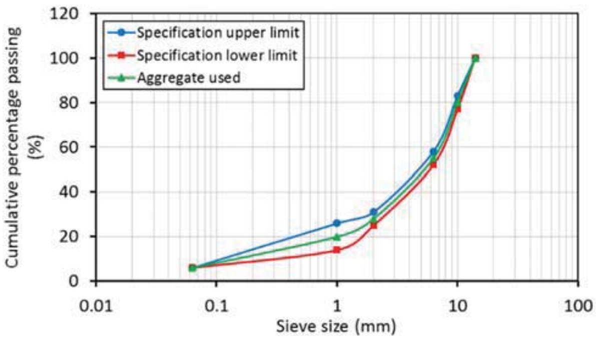

Fig. 1 14 mm close graded surface course

2) Filler

Filler is mainly a fine material that can pass through a sieve of 0.063 mm and it comes from aggregate or other types of comparable granular materials. One of the most common filler types is the limestone dust filler that was chosen to be used in this study. Filler is one of the most important bituminous mixture components, it has a significant impact upon the behaviour and properties of the resulting bituminous mixtures.

3) Bitumen Emulsion

The bitumen emulsion selection depends on the gradation and type of the used aggregate and the ability of emulsion to coat the aggregates. To achieve that, a cationic slow setting bitumen emulsion (C50B3) with 50% bitumen content was attempted and selected due to the high adhesion to aggregates. This type of emulsion is called Cold Asphalt Binder (CAB 50) based on 40/60 penetration grade base bitumen and is supplied by Jobling Purser, Newcastle, UK. The high stability and high adhesion of this cationic emulsion were the reasons for selection as recommended by the supplier.

B. Testing Program

1) Indirect Tensile Stiffness Modulus Test

The indirect tensile stiffness modulus (ITSM) test was used for the assessment of the mechanical properties of CBEMs [24]. Meanwhile the stiffness modulus ratio (SMR) was utilised for examination of the water sensitivity of the CBEMs. The ITSM test was conducted in compliance with [25]. This test simulates the viscoelastic response of the bituminous material. In this test, cylindrical specimens are prepared in the lab with a diameter of 100 mm and thickness of 63.5 mm. The test has been employed to measure small tensions on bituminous mixtures by applying intrinsic load over the vertical diameter of a cylindrical sample. ITSM test was conducted to determine the strength characteristics of the CAEMs. It was required to apply compressive loads to the specimen between two loading strips which transfers the loads to tensile stresses along the vertical diametric plane. The ITSM test was designed for testing the ability of individual pavement layer to distribute loads from traffic to the underneath layers. This test is a non-destructive test and usually employed in the evaluation of hot mix stiffness modulus. Currently, stiffness modulus is considered to be a very important indicator of performance in relationship to the properties of bituminous paving materials; the stiffness modulus can act as an indicator of the ability that bituminous layers can spread loads [26]. The stiffness modulus is also considered as a most significant property generated in both subgrade and base [27].

2) Water Sensitivity Test

Water sensitivity test or moisture damage was carried out in order to provide an evaluation of the produced CBEM durability; this was conducted in relation to the SMR according to [28]. Two sample sets were prepared in this test; dry and wet, in which of each set five parallel samples were prepared for each mixture type. The first set of samples were prepared and tested within the dry condition with the temperature set at 20 °C. Prior to extraction, the samples were prepared, compacted and left in the mould for 24 hours at lab temperature. Following extraction, the sample was left on a flat surface for another 7 days before testing. The samples in the second set were saturated as prepared and left in the mould for a total of 24 hours at lab temperature and then extracted and submerged into a water bath at 20 °C for 4 days. Following these procedures, the samples were transferred to the vacuum container for 10 minutes in a vacuum pressure of 6.7 kPa and then re-submerged for 30 minutes more under water. Following all these, the samples were submerged for three days in the water bath of warm water at temperature of 40 °C before being tested. Lastly, the second set had a stiffness modulus test at a temperature of 20 °C; by testing water sensitivity an evaluation of the loss of mixture strength can be found whilst the mixtures are actually in contact with water through a determination of the ration between the ITSM of the dry and wet specimens. Water sensitivity was calculated using the SMR as shown in (1):

$$SMR = (\text{wet stiffness} / \text{dry stiffness}) \times 100 \qquad (1)$$

3) Temperature Sensitivity

The investigation was carried out in relation to the sensitivity of CBEMs to the temperatures and in order to establish a type of methodology that could be used for rapid and economical experimental research in the future. The mixture temperature sensitivity was inspected at 45 ºC, 20 ºC and 5 ºC. Specimens were prepared with the OPC which was used as a filler replacement in different ratios of 6%, 3% and 0%.

C. Experimental Procedure

1) Washing, Drying and Sieving of the Aggregate

Aggregates that contain any dust might prevent the bonding of the aggregate with the asphalt binder and result in excessive loss from damage. Therefore, the aggregate washed and cleaned by water to remove all the fine particles or dust. Then, the aggregate dried using an electrical oven at 100 ºC. These sieves' sizes are 14, 10, 6.3, 2, 1, 0.063 mm and pan at the bottom.

2) Sample Preparation and Condition

CBEM samples were prepared according to the Marshall method for emulsified asphalt aggregate cold mixture designs (MS-14), as adopted by the Asphalt Institute [29]. According to this procedure, the pre-wetting water content, optimum emulsion content, optimum total liquid content at compaction and optimum residual bitumen contents were 3%, 12.4%, 15.4% and 6.2%, respectively. These results are comparable to those published by [21], [30], [31]. Samples were mixed using an electric blender as shown in Fig. 2 and to ensure a consistent distribution of the OPC, water and emulsion in the mixtures, the aggregate together with the OPC and the pre-wetting water were added and mixed for 1 minute. Gradually, during the following 30 seconds of mixing, the bitumen emulsion was added and then the mixing was continued for 2 minutes. In addition, the mixed samples were placed in the moulds, and then a Marshall hammer was employed for impact compaction with a total of 50 blows for each of the sample faces as shown in Fig. 3.

Two steps of samples curing were performed, firstly, compacted samples were kept in their moulds for one day at lab temperature (20 ºC), and then removed so that samples would not collapse. The samples were then in the second step extruded and placed in the lab temperature and ITSM was applied at the various times of curing (2, 7, 14, 28, 90, 180 and 360 days). For ITSM tests, five duplicate samples were tested and the average was taken for each individual value.

IV. Results and Analysis

A. ITSM Test

The results of the ITSM tests for the OPC substitution are shown in Fig. 4. It is obviously shown that adding OPC as a replacement to the limestone dust in CBEMs develops the stiffness modulus of such mixtures. These mixtures have ranges of OPC with different percentage (0%, 1%, 2%, 3%, 4%, 5% and 6%) of total weight of the dry aggregate.

The stiffness modulus and strength properties of CBEMs were considerably improved by increasing the ratio of OPC. The latter is widely used in CMA as a stabilizer added to enhance the early age efficiency of the mixture as well as reducing the curing time. This application shows that cement hydration improves the development of strength by means of consuming more water and thus stimulating the bitumen emulsion mixture. Fig. 4 shows that the increase in the OPC percentage followed by increasing the stiffness modulus of the CBEMs, especially in the early age. The stiffness modulus test was conducted in compliance to BS EN 12697-26:2004 at 20 ºC and investigated the impact of replacing the conventional mineral filler (limestone dust) with the different percentage of OPC. The OPC was employed in its several stages (2, 7, 14, 28, 90, 180 and 360 days).

Fig. 2 Electrical blender


Fig. 3 Marshall hammer

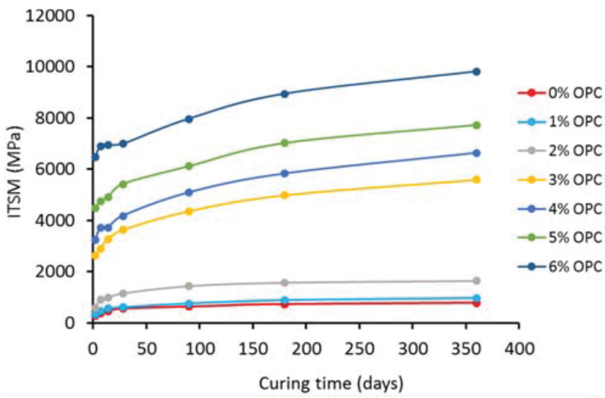

Fig. 4 ITSM of different mixtures with different curing times

B. Water Sensitivity Test

In this test, the loss of the strength of the CBEMs due to the water effect was evaluated by determining the ratio of the ITSM of the dry samples to the wet samples. This ratio is defined as the SMR in compliance [28]. Filler replacement with the OPC is significantly developed the durability of the CBEMs as shown in Fig. 5. The conventional bitumen emulsion mixtures have high risk of water damage during curing period. This means that the conventional CBEMs is affected by the issue of durability. Therefore, the mixtures can resist water damage by adding cement as a stabiliser. The bituminous specimens were prepared with three different mixtures in terms of OPC percentage (0%, 3% and 6%).

In terms of SMR, the water sensitivity of the CBEMs with 6% of OPC was improved more than other mixtures such as (0% and 3% OPC). It is clearly shown that the SMR of CBEM with 6% OPC is about 95% while 60% for 3% OPC and 50% for 0%. This indicates that adding OPC to the CBEMs reduces the effects of water damage.

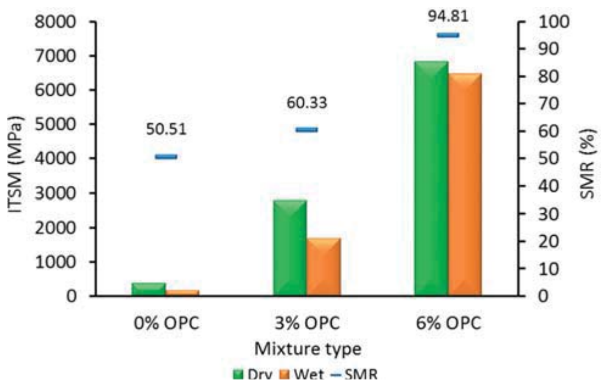

Fig. 5 Water sensitivity results

C. Temperature Sensitivity Test

The ITSM of CBEMs was determined after 28 days to assess the performance of CBEMs at different temperatures. The bituminous samples were tested at 5, 20 and 45 ºC and the temperature sensitivity results are shown in Fig. 6. The slope of the curves represents the temperature sensitivity of the mixtures. The mixtures having relatively higher rate of change show greater effect of temperature sensitivity. In this figure, it can be clearly seen that the maximum stiffness modulus occurred when the samples tested at the temperature 5 ºC and the stiffness decreased when the temperature increased to 45 ºC. Furthermore, by replacing limestone dust filler with the OPC, stiffness increased with the increasing of the OPC.

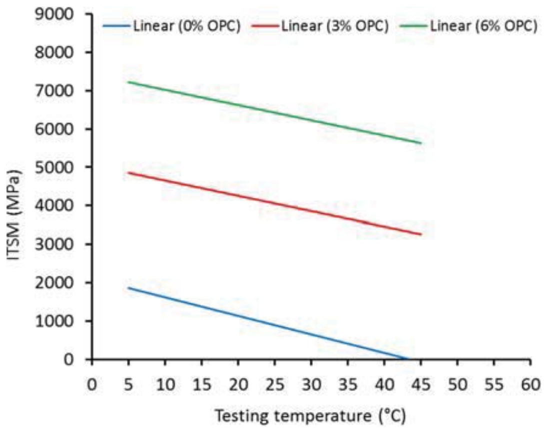

Fig. 6 Temperature sensitivity results

V. Conclusion

This experimental research focuses on the development of CBEMs treated by cement, and study the effects of cement on the enhancement of cold mix mechanical properties to be used as a layer at the surface of pavement roads. An assessment was undertaken the mechanical properties of the mixture that was produced through the ITSM and water sensitivity tests in relation to the SMR, which acted as a scale measuring durability improvement following the addition of OPC to the CBEMs. Depending on the specific materials utilised, some of CBEM problems were solved as below:

- The stiffness modulus increased significantly with increasing in content of OPC, and the results can be maximised when, for example, 6% OPC is used to replace the whole of the mineral filler. In addition, with CBEMs that have 6% OPC cured faster than other mixtures.
- According to the results related to durability, resistance to moisture damage was developed when 6% OPC used.
- CBEMs with 3% and 6% OPC had temperature sensitivity results showing significantly lower figures than conventional mixture with the modulus change of the stiffness slope.

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