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Enhancing the Mechanical Properties of Gap Graded Cold Asphalt Containing Cement Utilising By-Product Material

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Abstract: The little stiffness modulus, high voidage and long curing time has limited the use of CBEM's (cold bituminous emulsion mixtures) in road and highways to pavement experiencing low traffic. The aim of this study is to improve the properties of gap graded CRA (cold rolled asphalt) containing OPC (ordinary portland cement) as filler by addition of a by-product material as an activator. OPC was added to the CRA as a replacement to the conventional mineral filler (0%-100%), while LJMUA (Liverpool John Moores University Activator) was added as an additive in the range from 0%-3% by total mass of aggregate. Laboratory tests included stiffness modulus and uniaxial creep test to assess the mechanical properties. The results have shown a considerable improvement in the mechanical properties from the addition of LJMUA to the CRA containing OPC especially for the early life stiffness modulus that is the main disadvantage of the cold mixtures.

Key words: Stiffness modulus, creep stiffness, ordinary portland cement, cold rolled asphalt.

1. Introduction

HRA (hot rolled asphalt) surface course is a continuous gap graded mixture of mineral filler, sand and bitumen coarse aggregate is added to it. The mechanical properties of the mixture are controlled by the strength properties of the mortar, i.e., mineral filler, sand and bitumen. The material is widely used for surfacing major roads in UK because it provides a dense, impervious layer resulting in a weather resistant and durable surface able to withstand the demands of today's traffic loads, providing good resistance to fatigue cracking. Nevertheless, it might experience some weakness to deformation resistance [1].

Additionally, the use of CBEM's (cold bituminous emulsion mixtures) for road construction, rehabilitation and maintenance is gaining interest day by day, as these mixtures offer advantages over traditional hot mixtures in different terms such as, environmental impact, energy saving, cost effectiveness, safety and cheap production processes. In UK, today's use of cold mix takes less interest compared with HMA (hot mix asphalt), as this mixtures show low earlier strength to resist the different traffic loads and low resistance to water damage especially rainfall. Other countries such as USA, European countries and Australia showed more interest in the uses of the materials due to the above advantages [2].

Chevron Research Company in California after many research studies reported that full curing of cold bituminous mixtures on site depending on the weather conditions and curing times may extend from 2-24 months. Unfortunately, UK weather conditions are not assistant to decrease the curing time, humid, cold and rainy most time of the year [3].

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Several studies have been implemented on improving the mechanical properties of the cold mixes in terms of OPC (ordinary portland cement) addition. Initial study conducted by Head [4] and focused on the improvement on the Marshall Stability of the modified cold asphalt mix. He stated that Marshall Stability of modified cold asphalt mix increased by about three times with the addition of 1% OPC compared with un-treated mix.

Li et al. [5] conducted experiments to assess the mechanical properties of a three-phase CAEC (cement-asphalt emulsion composite). Through experimental study, they showed that CAEC possessed most of the characteristics of both cement and asphalt, namely the longer fatigue life and lower temperature susceptibility of cement concrete, and higher toughness and flexibility of asphalt concrete.

Oruc et al. [6] implemented experiments to assess the mechanical properties of emulsified asphalt mixtures having 0-6% OPC. The test results revealed considerable improvement with high OPC addition percentage. Furthermore, they recommended that the cement modified asphalt emulsion mixes might be used as structural pavement layer.

Another study implemented by Wang and Sha [7] indicated that the rise of cement and mineral filler fineness has a positive impact on micro hardness of the interface of aggregate and cement emulsion mortar. Moreover, they concluded that the limestone and limestone filler impact hardness value are highly when compared with granite and granite filler.

The main aim of this research is to improve the mechanical properties of gap graded CRA (cold rolled asphalt) containing OPC instead of conventional filler by addition of a by-product material. To achieve this aim, LJMUA (Liverpool John Moores University Activator) was used as additive in the range from 0%-3% by total mass of the aggregate to the CRA containing different amounts of OPC. Stiffness modulus and uniaxial compressive cyclic creep tests were used to assess the mechanical properties in this investigation.

2. Experimental Program

2.1 Materials Properties

The coarse and fine aggregate used in this investigation were crushed granite and their physical properties are shown in Table 1. Two types of filler were used in this study, traditional mineral filler (limestone dust) and OPC, and a high silica (more than 75% SiO_2) by-product material with 10 microns average particle size has been used as an additive, i.e., LJMUA. The aggregate was dried, riffled and bagged with sieve analysis achieved in accordance with BS EN 933-1 [8].

The cationic slow setting bituminous emulsion (K3-60) was used to produce the novel CRA to develop high adhesion between aggregate particles. In contrast, a 125-pen and 50-pen bitumen grades were used to produce the traditional HRA. The properties of the selected bituminous emulsion and bituminous binder are shown in Table 2.

2.2 Selected Gradation

The aggregate gradation of wholly mixtures (CRA and HRA mixtures) used in this study was based on BS EN 13108-4 [9] for HRA, 55/14C gap graded surface course mixture gradation has been used in this work. The selected gradation is shown in Table 3.

2.3 Preparation of CRA and HRA Mixtures

The design procedure for the new CRA mixtures used in this investigation was based on the method adopted by the Asphalt Institute (Marshall Method for Emulsified Asphalt Aggregate Cold Mixture Design (MS-14)) [10]. According to this procedure pre-wetting water content, optimum total liquid content at compaction and optimum residual bitumen content were 5%, 15.16% and 7%, respectively.

Table 1 Physical properties of aggregate.

Material	Bulk specific gravity (g/cm^3)	Apparent specific gravity (g/cm^3)	Water absorption (%)
Coarse aggregate	2.79	2.83	0.6
Fine aggregate	2.68.	2.72	1.6
Mineral filler	2.71	-	-

Table 2 Bituminous binder and bitumen emulsion properties.

Bitumen emulsion (K3-60)		Bituminous binder (40-60)		Bituminous binder (100-150)	
Property	Value	Property	Value	Property	Value
Appearance	Black to dark brown liquid	Appearance	Black	Appearance	Black
Boiling point (ºC)	100 ºC	Penetration at 25 ºC	43	Penetration at 25 ºC	122
Relative density at 15 ºC (g/ml)	1.05	Softening point (ºC)	54	Softening point (ºC)	43.6
Residue by distillation (%)	64	Density at 25 ºC	1.02	Density at 25 ºC	1.05

Table 3 Aggregate gradation for 55/14C gap graded surface course (BS EN 13108-4).

Sieve size, mm	20	14	10	2	0.5	0.25	0.063
Percent passing (specification range)	100	98-100	42-63	40	19-31	9-31	6
Percent by mass (passing mid)	100	99	52	40	25	20	6

Different percentages of OPC (0%, 1.5%, 3%, 4.5% and 6% by total mass of aggregate) as a replacement for the conventional mineral filler were used in preparation of the specimens of CRA mixtures. On the other hand, a by-product material (LJMUA) was used as an additive to the CRA mixtures containing OPC with a range of 0%-3% by total mass of aggregate. In contrast, HRA mixture samples were prepared with the same aggregate type and gradation, 5.5% optimum binder content was used according to the BS 594987 Annex H [11] for the 55/14C HRA surface course design mixture. Both cold and hot mixes were prepared to produce three specimens for each specific mix. The cold mix specimens were mixed and compacted at lab temperature, i.e., 20 ^{o}C, while 125-pen and 50-pen hot mix specimens were mixed at (150-160 ^{o}C) and (160-170 ^{o}C), respectively.

2.4 Curing of the CRA Samples

The conditioning of the CRA specimens is depending on the procedure adopted by the Asphalt Institute MS-14 [10]. The curing process involves two stages: The first stage was achieved with 24 h @ 20 ^{o}C as the sample needs to be left in the mould before being extruded to prevent specimen disintegration; while stage two was achieved with 24 h @ 40 ^{o}C (the samples have been left in the ventilated oven). After these stages, the samples have been left in the lab (20 ^{o}C) and tested at different ages, i.e., 2, 7, 14 and 28 days to indicate the indirect tensile stiffness modulus. This curing process, i.e., 24 h @ 20°C plus 24 h @ 40°C represents 7-14 days in the field as reported by Jerkins [12].

3. Testing

3.1 ITSM (Indirect Tensile Stiffness Modulus)

The test is conducted at 20 ^{o}C in accordance with BS EN 12697-26:2004 [13], Cooper Research Technology HYD 25 apparatus was used (Fig. 1).

3.2 UCCT (Uniaxial Compressive Cyclic Test)

The UCCT is a destructive test used mainly to evaluate the permanent deformation characteristics of hot mixes. UCCT at 40 ^{o}C was used to assess the effect of addition of LJMUA to the CRA containing OPC on creep performance. The test was conducted in accordance with BS EN 12697-25 [14], also Cooper Research Technology HYD 25 testing apparatus was used (Fig. 2).

Fig. 1 HYD 25 indirect tensile apparatus.

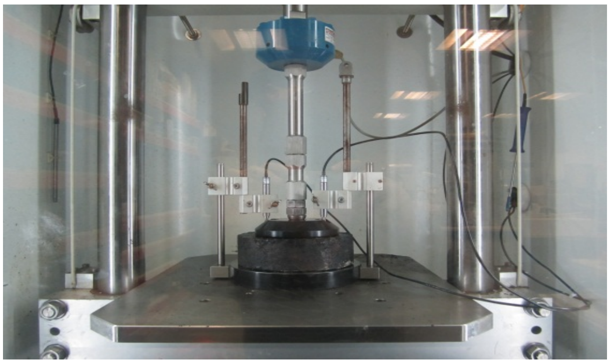

Fig. 2 Creep test configuration.

4. Results and Discussion

4.1 ITSM Results

The specimens were tested according to BS EN 12697-26:2004 [13] at ages 2, 7, 14 and 28 days to assess the effect of replacement of conventional mineral filler with OPC as well as the addition of LJMUA to these mixtures, as shown in Figs. 3-5. It is obviously shown that the addition of OPC instead of filler in the CRA increased the stiffness modulus considerably. This enhancement in ITSM results is due to firstly, another binder was generated in addition to the bitumen residue binder produced from the hydration process of the hydraulic reaction of OPC and secondly loss of the trapped free water which is absorbed by OPC.

Also there is incredible enhancement to the stiffness modulus from the addition of LJMUA to the CRA containing OPC within the early life of mixtures. It is clearly shown that addition of 2% LJMUA to the CRA containing 3% OPC increased the stiffness

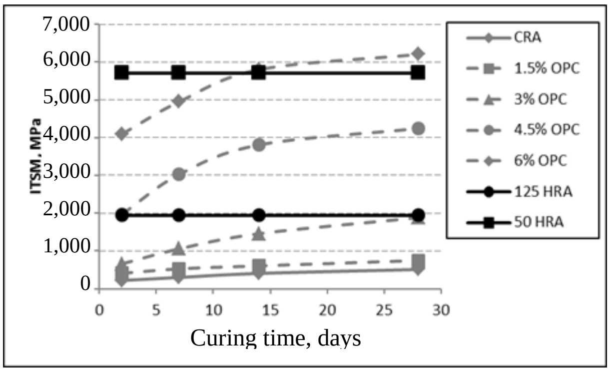

Fig. 3 Influence of curing time and OPC percentage on SM results.

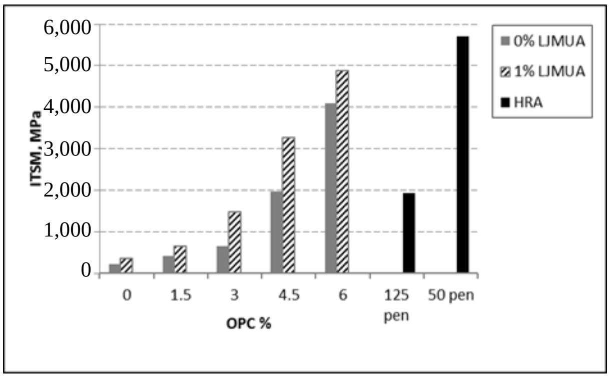

Fig. 4 Influence of addition of 1% LJMUA to CRA containing OPC after two days.

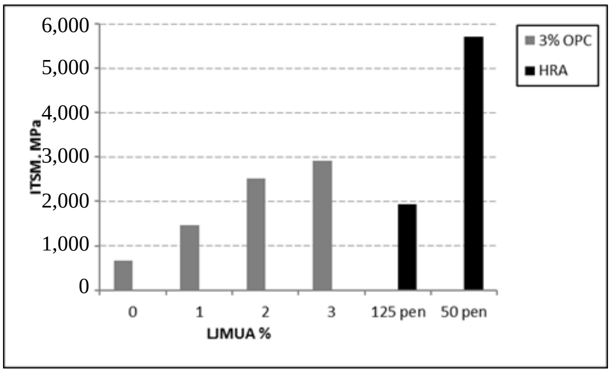

Fig. 5 Influence of addition of LJMUA to CRA containing 3% OPC after two days.

modulus more than three times and its value is more than the target value for the 125-pen HRA, i.e., 1,941 MPa. This further improvement is due to the degree of hydration of OPC is increased when the high silica ash, i.e., LJMUA were added in the CRA mixtures and was working as an activating agent to OPC. This finding corroborates the ideas of Dillshad [15], who found similar effect by incorporating high silica material in OPC system.

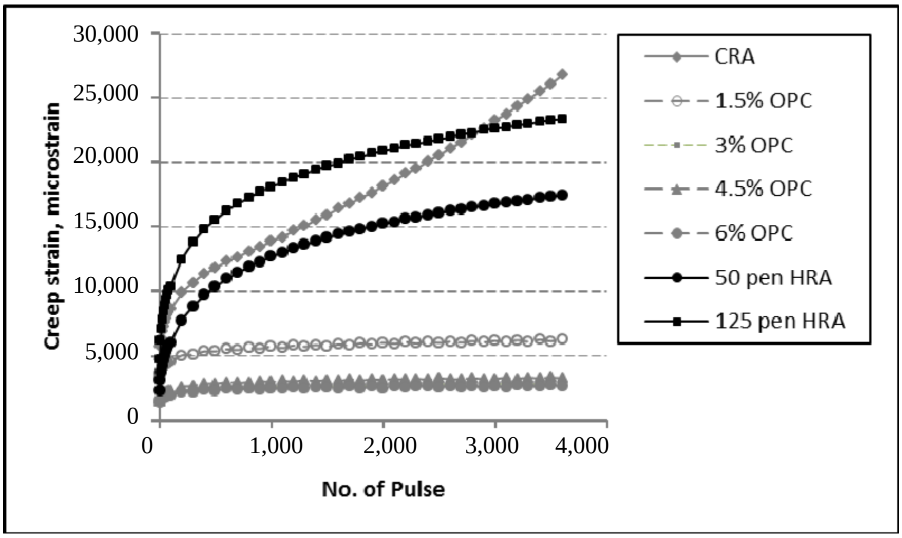

Fig. 6 Creep strain versus number of pulse applications of specimens with different percent of OPC.

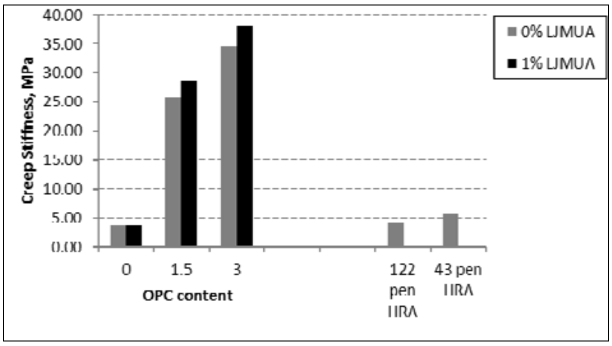

Fig. 7 Influence of percent of LJMUA on ultimate creep stiffness of CRA containing OPC.

4.2 UCCT Results

Figs. 6 and 7 show the results of the UCCT tests for CRA containing cement with and without LJMUA. The creep strain versus number of pulse applications for CRA containing OPC is shown in Fig. 6, while Fig. 7 displays the effect of addition of 1% LJMUA to the CRA containing 1.5% and 3% OPC on creep stiffness.

These figures reveal the positive effect of OPC on the creep properties of CRA, specimens with 1.5% OPC decrease the creep strain incredibly compared to the control specimens as well as HRA mixtures. On the other hand, there is no ad the addition of LJMUA to the CRA mixtures containing OPC on the creep performance of these ditional outstanding from mixtures.

5. Conclusions

Adding the by-product material LJMUA to the CRA containing OPC as mineral filler provides a promising enhancement to the mechanical properties of the new CRA mixtures (especially stiffness modulus) to a level that they are comparable with those of HRA mixtures.

The main conclusions drawn from this investigation are as follows:

(1) The replacement of the conventional mineral filler with OPC into the CRA mixtures improves significantly the stiffness modulus results especially with higher percentages of filler replacement (4.5% and 6%);

(2) The addition of LJMUA increases considerably the stiffness modulus of the CRA containing OPC. Addition of 1% of LJMUA to the CRA containing 3% OPC improves the stiffness modules more than twice and addition of 2% LJMUA increases it to more than three times (its value is more than the target point for the conventional 125-pen HRA);

(3) The replacement of conventional mineral filler with OPC can also improve the permanent deformation resistance when compared to both control CRA and traditional HRA. The creep stiffness improves more than 6 times for the CRA containing

just 1.5% OPC compared with the control CRA;

(4) There is no further outstanding from the addition of LJMUA to the CRA containing OPC, i.e., the creep performance for the CRA containing OPC with or without LJMUA is better than the performance of the control CRA as well as HRA prepared with 50-pen and 125-pen bitumen.

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