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Performance of gap graded cold asphalt containing cement treated filler

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HIGHLIGHTS

- New gap-graded Cold Rolled Asphalt is generated using OPC instead of mineral filler.
- Performance of CRA mixtures investigated at moderate temperature i.e. 20 °C.
- Fast curing CRA containing OPC has been revealed.
- Fatigue life and crack propagation for the produced CRA mixtures examined.

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ABSTRACT

Previous studies have revealed the beneficial effects of adding Ordinary Portland Cement (OPC) to Bitumen Emulsion Mixtures (BEMs). These effects were confirmed for some dense graded mixtures based on recipes currently used for hot asphalt concrete mix in the UK and being considered for usage in BEMs. On the other hand, Hot Rolled Asphalt (HRA) which is a gap graded mixture is extensively used for surfacing major roads in the UK because it provides a dense, impervious layer, resulting in a weather-resistance durable surface able to endure the demands of modern traffic loads and providing good resistance to fatigue cracking.

This laboratory study describes the development of novel gap-graded Cold Rolled Asphalt (CRA) by using OPC instead of conventional mineral filler. Stiffness modulus, uniaxial creep, four point load fatigue, and semi-circular bending monotonic tests were used to assess the mechanical properties while stiffness modulus ratio was determined to assess the water sensitivity of the produced mixtures.

The study concluded that there is a considerable enhancement in the mechanical properties and water sensitivity of CRA containing OPC. Also, the produced cement treated gap-graded CRA shows a significant lower thermal sensitivity than conventional HRA. More interestingly, the new cement treated CRA is found to be comparable with the mechanical properties of the conventional HRA after less than 1 day.

1. Introduction

Gap graded Hot Rolled Asphalt (HRA) is extensively used for surfacing major roads in the UK as it provides a dense, impervious layer, resulting in a weather resistant durable surface able to endure the demands of high traffic loads. At the same time it also offer a good resistance to fatigue cracking [18].

Reduction of adverse environmental impact and safety during manufacturing and construction are the main issues encouraging the use of cold Bituminous Emulsion Mixture (BEM) instead of hot mix asphalt (HMA) in roads and highways construction. Moreover, decreasing wastes from aggregate production processes, reducing land-filling and reducing CO_2 emissions during hot bituminous mixture production and laying are the main target schemes for the environmentally unfriendly processes [22].

After research studies implemented by Chevron Research Company in California, it was reported that the full curing of BEMs on-site depends on the weather conditions as well as curing periods might take from 2 to 24 months. Unfortunately, the UK weather conditions are not conducive to short curing times; being prone to being humid, cold, and rainy for much of the year [13].

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There are many investigations that have been undertaken to upgrade the mechanical properties of the cold BEMs utilising virgin natural materials. The most common hydraulic binders used in the UK comprise Ordinary Portland Cement (OPC), Ground Granulated Blast Furnace Slag (GGBS) and lime, whereas, cement is the most extensively used cementitious components for cold BEMs.

A study conducted by Head [11] focussed on the development on Marshall Stability of the modified cold asphalt mix and reported that Marshall Stability of modified cold asphalt mix increase by about three times with the addition of 1% OPC compared with un-treated mix. Furthermore, Milton and Earland [15] indicated that cement may be required either as the primary binder or as a supplementary binder to act as an adhesion agent or help to improve the short term properties of the compacted mixtures.

Needham [16] and Brown and Needhem [3] showed that incorporation of cement into dense graded cold BEMs can enhance the stiffness modulus, resistance to permanent deformation, resistance to fatigue cracking (at an initial strains below 200 micro strain) and resistance to water damage.

An experimental study was carried out by Li et al. [14] for assessing the mechanical properties of a three-phase Cement–Asphalt Emulsion Composite (CAEC). This study reported that CAEC demonstrate the longer fatigue life and lower temperature susceptibility of cement concrete, and the higher toughness and flexibility of asphalt concrete.

Furthermore, laboratory studies carried out by Giuliani [10] illustrated that by incorporation of cement into the emulsion, improved performance of the treated mixtures can achieved when compared with that of traditional hot mix asphalt. He also stated that cement proved to be a regulating element of the emulsion breaking, by increasing the viscosity of the bitumen and contributing to the creation of new bonds in the mixture. Physical and chemical properties of asphalt mixtures are influenced by cement addition, even with small doses. Giuliani [10] also observed that cement addition has a beneficial action in producing an excellent creep performance and a high stiffness modulus in laboratory samples, even after they were submerged in water.

Pouliot et al. [21] introduced a detailed study in terms of hydration process, the microstructure and the mechanical properties of mortars with a new mixed binder which are prepared from a cement slurry and a small quantity of anionic bitumen emulsion (SS-1) or cationic bitumen emulsion (CSS-1). They concluded that the existence of a small quantity of emulsion had an effect on the hydration process of cement. In addition, they found that the cationic slow setting emulsion (CSS-1) showed higher mortar strengths and elastic modulus compared with anionic emulsion (SS-1).

Oruc et al. [20] implemented experiments to assess the mechanical properties of emulsified asphalt mixtures having 0–6% OPC. The test results revealed considerable improvement with high proportional additions of OPC. Furthermore, they recommended that the cement modified asphalt emulsion mixes might be used as a structural pavement layer.

Another study, conducted by Thanaya et al. [23], concluded that the addition of 1–2% rapid-setting cement increased the strength development and improved the mechanical properties of the modified cold mixes, especially in the early days.

The study implemented by Wang and Sha [24] reported that the rise of cement and mineral filler fineness has a progressive impact on the micro-hardness of the interface of aggregate and cement emulsion mortar. Also, they concluded that the limestone and limestone filler impact hardness values are higher than those for granite and granite filler.

HRA is a gap graded mixture and widely used for surfacing the major roads in the UK. Although, extensive research has been carried out on incorporating of OPC in different types of BEMs, no single study exists which is dealing with producing a gap graded BEM suitable for a heavily trafficked surface course using standard bitumen emulsion and incorporating OPC. Therefore, the main aim of this study was to develop a new gap-graded Cold Rolled Asphalt (CRA) by replacing the conventional mineral filler with OPC. The mechanical properties and water sensitivity of the new CRA containing OPC were studied to assess the performance of the new mixtures as well as comparative study with the control CRA and conventional HRA mixtures. The mechanical properties were assessed by the stiffness modulus, uniaxial creep tests, fatigue test and semi-circular bending monotonic test, while the water sensitivity was investigated to assess the durability of the produced CRA in terms of the stiffness modulus ratio.

2. Materials and testing

2.1. Materials

The coarse and fine aggregate used in this investigation were crushed granite from Bardon Hill quarry normally used to produce HRA mixtures. The physical properties of the aggregates have been shown in Table 1. The aggregates were dried and sieved as per BS EN 933-1 [9] to achieve the required gradation.

Cationic slow setting bitumen emulsion (C56B7) was used to prepare all the new CRA mixtures with and without replacement to the conventional mineral filler. According to Nikolaides [19], cationic emulsion is more preferable due to its ability to coat the given aggregate and to ensure high adhesion between aggregate particles. Table 2 shows the properties of the selected bitumen emulsion.

On the other hand, two grades of bitumen has been used to produce HRA mixtures which were 100/150 and 40/60. The properties of these bitumens are illustrated in Table 3.

Limestone dust was used as conventional mineral filler, while OPC was used as hydraulic filler by replacing the conventional mineral filler in a range from 0% to 6%.

2.2. Selected gradation for CRA and HRA

55/14C gap-graded surface course mixture gradation has been used to prepare CRA and HRA mixtures based on BS EN 13108-4 [6] for HRA; the selected gradation illustrates in Table 4.

2.3. Sample preparation

The mix design of CRA mixtures was based on the Asphalt Institute design procedure (Marshall Method for Emulsified Asphalt Aggregate Cold Mixture Design (MS-14)) [1]. Different pre-mixing water contents were incorporated, i.e. 3–6% by mass of aggregate with Initial Emulsion Content (IEC), calculated from Eqs. (1) and (2) (IEC = 6.58%), to indicate the lowest pre-mixing water content with adequate coating. According to the visual inspection, 3% pre-mixing water content was chosen in preparation of CRA mixtures.

$$p = (0.05\,A + 0.1\,B + 0.5\,C) \times (0.7) \tag{1}$$

where

P = the percentage of IRBC by mass of total mixture.
A = the percentages of coarse aggregate (retained on sieve 2.00 mm).
B = the percentages of fine aggregate (passing sieve 2.00 mm and retained on sieve No. 0.063 mm).
C = the percentages of filler (materials passing 0.063 mm).

While the second step is determination of IEC from another empirical formula as show below:

$$\text{IEC} = (P/X) \tag{2}$$

Table 1
Aggregate's physical properties.

Material	Property	Value
Coarse aggregate	Bulk particle density, mg/m^3	2.79
	Apparent particle density, mg/m^3	2.83
	Water absorption, %	0.6
Fine aggregate	Bulk particle density, mg/m^3	2.68
	Apparent particle density, mg/m^3	2.72
	Water absorption, %	1.6
Mineral filler	Particle density, mg/m^3	2.71