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Superior cold rolled asphalt mixtures using supplementary cementations materials

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HIGHLIGHTS

- New ternary blended cementitious fillers i.e. TBF-1 and TBF-2 are generated from blending different SCM.
- Superior CRA mixtures were developed using novel TBF-1 and TBF-2 as a replacement to mineral filler.
- A significant outstanding in terms of mechanical properties and water sensitivity for the novel CRA mixtures was achieved.
- New cementitious binder produced totally from waste materials which is comparable with traditional OPC.

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ABSTRACT

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-resistant durable surface able to endure the demands of modern traffic loads and providing good resistance to fatigue cracking.

This paper describes a laboratory study on the production of new, superior, cold Bitumen Emulsion Mixtures (BEMs) with the same gradation used with conventional HRA mixtures and collectively incorporating different types of supplementary cementitious materials (SCM) instead of the conventional mineral filler. Accordingly, two ternary blended fillers termed as TBF-1 and TBF-2, have been blended from different SCMs and optimised to replace the conventional mineral filler.

To develop the gap-graded Cold Rolled Asphalt (CRA) mixtures evaluation of stiffness modulus, creep performance and fatigue testing was used to assess the mechanical properties while stiffness modulus ratio was used to investigate the water sensitivity.

The study concluded that there is a substantial improvement in the mechanical properties and water sensitivity of CRA containing TBF-1 and TBF-2. Also, the superior CRA mixtures produced showed a significant lower thermal sensitivity than conventional HRA. More remarkably, the new CRA were found to be comparable with the conventional HRA after a very short curing time (after 4 h).

1. Introduction

Hot Rolled Asphalt (HRA) is widely used for surfacing major roads in the UK because it provides a dense, impervious layer, resulting in a weather resistant durable surface able to endure the demands of today's traffic loads and providing good resistance to fatigue cracking. However it may experience some weakness to permanent deformation resistance [20].

On the other hand, the technology of cold bituminous emulsion mixtures (BEMs) (one of the cold asphalt technologies) for road pavements means manufacturing of asphalt mixtures using bitumen emulsion as binder at ambient temperature. This has been widely utilised in many countries. The USA and France have been utilising materials since the 1970s and appear to have extensive experience in the performance of BEM. Meanwhile, due to the relatively wet/cold climatic conditions in the UK, which are not favourable to the emulsion curing process, the use of BEM was not embraced [16]. However, in the UK, the publication of "Specification for Reinstatement of Opening in Highways" in 1992 by the Highway Authority and utility Committee (HAUC) allowed

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the use of cold laid asphalt mixtures instead of hot mixtures for reinstatement works in low volume roads and footways [15].

Environmental conservation campaigners, energy savings and safety are the main issues in favour of the use of BEM instead of hot mixtures in highways construction. In terms of the environmental conservation considerations; decreasing wastes from aggregate production processes, reducing land-filling and reducing CO_2 emissions during production and laying of hot bituminous mixtures are the main target schemes for the environmentally unfriendly processes [28]. BEM is an attractive method of producing bituminous mixtures to tackle the mentioned disadvantages whilst incorporating some waste and/or by-product materials individually or collectively in these mixtures.

There are some concerns with using BEMs as stated by previous studies and applications. However, a major problem with this kind of application is with the long curing time (evaporation of trapped water) required to achieve the maximum performance and the poor early life strength (because of the existence of water). The Chevron Research Company conducted laboratory and field studies to assess the performance of BEMs in California. They stated that the full curing in field of these mixtures may occur between 2 and 24 months depending on mixture's ingredients and weather conditions [16].

There are many investigations that have been undertaken to upgrade the mechanical properties of the cold BEMs utilising virgin materials. The most common hydraulic binders used in the UK comprise Portland cement, Ground Granulated Blast Furnace Slag (GGBS) and lime. Cement is the most extensively used cementitious components for cold BEMs [14,18,4,24].

Oruc et al. [22] conducted experiments to assess the mechanical properties of emulsified asphalt mixtures having 0–6% Portland cement. The test results revealed considerable improvement with high proportion additions of Portland cement. Furthermore, they recommended that the cement modified asphalt emulsion mixes might be used as a structural pavement layer.

Considering the above disadvantages of BEMs and the benefits of incorporating cementitious filler, this study investigated possible ways for the development of new BEMs with gap-graded mixtures similar to conventional HRA gradation which would be suitable for surface course on heavily trafficked pavements. The new product is termed throughout this study as Cold Rolled Asphalt (CRA). Although extensive research has been carried out on producing different types of BEMs, no single study exist which deals with producing a gap-graded BEM suitable for heavily trafficked surface course using standard bitumen emulsion and incorporating supplementary cementitious materials individually or collectively.

2. Materials and testing

2.1. Materials

The coarse and fine aggregates used in this investigation were crushed granite from Bardon Hill quarry normally used to produce HRA mixtures; Table 1 shows their physical properties. The aggregates were dried and sieved as per BS EN 933-1 [13] to achieve the required gradation.

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

Cationic slow setting bitumen emulsion (C 56 B 7) was used to prepare all the new CRA mixtures with or without replacement to the conventional mineral filler. According to [21], cationic emulsion is 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 (100/150 and 40/60) have been used to produce HRA mixtures and Table 3 illustrates the properties of these binders.

2.2. Selected gradation for CRA and HRA

In comparison to the high performance of HRA surface course mixtures specifically, high stiffness values with low air void content were disadvantages of the produced BEMs. The author, with his supervisory team, and after a healthy discussion with Liverpool Centre for Materials and Technology (LCMT) industrial partners, decided to develop a new BEM/s with a gap-gradation conventionally used for HRA surface course mixtures. Accordingly, 55/14C gap-graded surface course mixture gradation was used to prepare CRA and HRA mixtures based on BS EN 13108-4 [11] for HRA; Fig. 1 shows the selected gradation.

2.3. General sample preparation procedure

The procedure adopted by the Asphalt Institute (Marshall Method for Emulsified Asphalt Aggregate Cold Mixture Design (MS-14)) has been used to indicate the initial mix design constituents for CRA mixtures [2]. Consequently pre-mixing water content, optimum total liquid content at compaction and optimum residual bitumen content were 3%, 15.5% and 7%, respectively.

Specimens of CRA mixtures were mixed using a Hobart mixer. The aggregate and filler material with pre-wetting water content (3%) were added and mixed for 1 min at low speed. Bitumen emulsion (12.5%) was added gradually during the next 30 s of mixing, and the mixing was continued for 1.5 min at the same speed. This mixing method is termed as normal mixing throughout this study. Also, a standard Marshall Hammer (impact compactor) was utilised with 50 blows to each face of the 100 mm diameter specimens.

On the other hand, two types of HRA mixtures were prepared with different bitumen grade for comparison with the produced CRA mixtures which were 100/150 and 40/60 penetration grades. HRA mixtures were prepared with the same aggregate type and gradation; 5.5% optimum binder content for each type of bitumen was added based on the BS 594987 Annex H for the 55/14C HRA surface course design mixtures [3]. 100/150 and 40/60 HRA mixtures were mixed at (150–160 °C) and (165–175 °C), respectively.

2.4. Selected supplementary cementitious materials

The conventional mineral filler was limestone dust while Ordinary Portland Cement (OPC) was used as comparable cementitious filler. Table 3 shows the chemical analysis of the individual materials. Two types of ground waste Fly Ash (FA1 and FA2) were used to produce a Binary Blended Filler (BBF), while Silica Fume (SF) and a ground Bottom Ash (BA) were used individually to produce a new ternary blended filler i.e. TBF-1 and TBF-2 when incorporated with the previous BBF.

FA1 and FA2 are industrial waste materials which resulted from incineration of by-product materials in a power generation plant. The X-ray powder diffraction (XRPD) pattern of dry FA1 shows the sample is crystalline as it contains sharp peaks and low background, Fig. 2. As shown in this figure, Calcite ($CaCO_3$), Lime (CaO), Gehlenite ($CaAl[AlSiO_7]$), Merwinite ($Ca_3Mg(SiO_4)_2$, Belite (Ca_2SiO_4), and Mayenite

Table 2
Properties of (C 56 B7) bitumen emulsion.

Bitumen emulsion (C 56 B 7)	
Property	Value
Appearance	Black to dark brown liquid
Relative density at 15 °C, g/ml	1.05
Residue by distillation, %	56
Boiling point, °C	100 °C

Table 3
Properties of 100/150 and 40/60 bitumen binders.

Bituminous binder 40/60		Bituminous binder 100/150	
Property	Value	Property	Value
Appearance	Black	Appearance	Black
Penetration at 25 °C	43	Penetration at 25 °C	122
Softening point, °C	54	Softening point, °C	43.6
Density at 25 °C	1.02	Density at 25 °C	1.05