Comparison between laboratory results for cold recycled bound materials and DBM 50 used in airfield pavements

Helena Isabel Lacalle Jiménez[1, 2, a], Nicholas Thom[2, b], J. Paul Edwards[1, c]

[1] *Pavement Design and Asset Management, Civil and Infrastructure, AECOM, Nottingham, United Kingdom*
[2] *NTEC, University of Nottingham, Nottingham, United Kingdom*

[a] helena.lacalle@aecom.com
[b] Nicholas.Thom@nottingham.ac.uk
[c] j.paul.edwards@aecom.com

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ABSTRACT

Cold recycled materials are widely used in UK road construction, but their use in airfield pavements is less common. The UK has adopted the concept of sustainable development and cold recycling of asphalt into foamed or emulsion bitumen bound materials minimizes the waste generation and reduces the consumption of finite resources. In addition, this technique has the added benefit of readily incorporating recycled asphalt which contains tar, making cold recycling an attractive option for the rehabilitation of airfield pavements. The challenge is that there is no specific pavement design guidance for these materials and the current practice is to conservatively equate these materials to an assumed performance of a hot asphalt mixture. The objective of this paper is to verify if this practice is accurate when analyzing these materials' performance, especially through laboratory testing. The results presented in this paper show that the pavement design could be optimized and that a design guide based on cold recycled materials is needed to gain confidence and extend the use of cold recycled bitumen bound materials in airfields. This conclusion forms the basis for the SUP&R ITN project ESR1: "Pavement design for cold recycled materials".

Keywords: Cold Asphalt, Foam, Mechanical Properties, Reclaimed asphalt pavement (RAP) Recycling

1. INTRODUCTION

The construction industry is playing a key role in improving the efficient use of materials, as part of sustainable development; by addressing what, where and how it builds; and by planning for maintenance, future development and disposal [1]. In the context of pavements, the main aims for the efficient use of materials are to reduce demand on primary resources and divert materials from going to landfill as waste. Recycling asphalt is a pavement rehabilitation technique which involves recycling materials from the layers constituting a pavement that has already been in-service. These materials have often lost some of their original properties due to mechanical deterioration and/or ageing; such as cohesion, texture and composition; however the materials still have the potential for being recycled and forming new layers [2].
The potential benefits of the wider use of recycled materials within pavement designs include:

- Reduced demands on the environment for finite resources (e.g. primary aggregate abstraction and bitumen).
- Reduced demand on the environment (reduction in material for landfill).
- Potential for comparative benefits in pavement layer performance, facilitating reductions on the overall thickness of pavement design.

Material recovered from aged asphalt pavements is known as RAP (Reclaimed Asphalt Pavement) and it has the potential to be recycled into various applications dependent on its characteristics. RAP can be used in all pavement applications [3] but it is normally used in unbound mixtures for sub-base [4] , hydraulically bound mixtures for sub-base and base [4] and bitumen bound layers [5]. The objective should be to increase the RAP content in asphalt mixtures without sacrificing durability. The main benefit of using RAP into asphalt is the reduction in demand on bitumen, which is a finite resource. In the other hand, UK pavements constructed prior to 1980 or surfaced in the late 1980's may contain tar. Tar is a potentially hazardous material, in terms of waste disposal, and it is classified as "Hazardous Waste" by European Directives which were implemented in the UK via the Hazardous Waste Regulations 2005 (HWR). Pavements built during those years are now commonly requiring reconstruction and the problem is that when RAP contains tar, there are some limitations on use based on health and/or environmental considerations [6]:

- Bituminous materials with polycyclic aromatic hydrocarbons (PAH) over 25 mg/kg should not be recycled into hot mix asphalt.
- Bituminous materials with PAH over 1000 mg/kg and Benzo(a)pyrene levels above 100 mg/kg are not permitted to be recycled into unbound applications.
- The acceptable threshold values of total PAH and Benzo(a)pyrenes are 1000 mg/kg and 100 mg/kg respectively. Above these limits the material is classified as Hazardous Waste, if disposed.

This means that tar layers cannot be recycled into hot mix asphalt or unbound applications and their disposal is relatively expensive. Therefore, cold recycling is a safe and sustainable option for asphalt plannings containing tar and has become increasingly interesting, as it is a method which not only minimizes waste and use of raw material, but also saves energy because it is not necessary to heat the mixture [6].
Once the possibility of cold recycling a pavement is considered, the next step is to identify the recycling agent to be used. These agents extract maximum value from the old or aged binders in RAP. The most common agents used are foamed bitumen and bitumen emulsion [7].
This research will focus on cold recycled bound materials (CRBM) using foamed bitumen as it is the most commonly used cold technique in UK road construction, although their use in airfield pavements is less common. The problem is that there is no specific pavement design guidance for these materials and the current practice is to conservatively equate these materials to an assumed performance of a hot asphalt mixture.
CRBM will be used in the base layer of the pavement, so to ascertain the suitability of this practice CRBM performance will be compared to a hot asphalt base, namely Dense Bituminous Macadam 50 (DBM50).

2. LITERATURE REVIEW

2.1 Foamed Bitumen

Foamed bitumen is produced by injecting air and water droplets under high pressure (5 bars) into hot (typically 160-180°C) liquid bitumen, resulting in bitumen taking the form of foam as schematically illustrated in Figure 1. The volume of bitumen will increase while viscosity considerably reduces [7].
Normally between 3% and 5% of foam bitumen is added to the mixture, but when the recycled material contains a high proportion of bitumen, this can be reduced to 2% or 3% [8], [7], [2]. Foamed bitumen has been used with success in roads and airfields, having similar strength and stiffness to conventional hot mixes after a period of curing, and giving the pavement good structural performance [9].

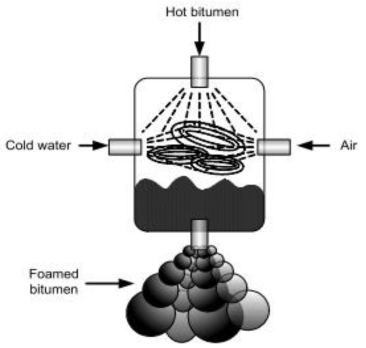

Figure 1: Foamed bitumen production [7]

2.2 Curing of CRBM

It is accepted that hot mix asphalt reaches its mature state after a very short time. This means that its characteristics can be measured almost immediately after paving. But this is not the case for CRBM mixes [10].
CRBM mixes are evolutive materials, as the initial cohesion between the binder and the aggregates is relatively low and it grows gradually. These materials only reach their mature state after a period of time [10]. This period of time is called the curing phase and opening to traffic and long term performance depends on it [11] as this material only develops full strength after a large percentage of its moisture content is lost [12].
The objective of curing specimens in the laboratory is to simulate pavement conditions as experienced in the field. There are several studies on curing procedures and some guidance notes [5][13], but the problem is that no standard curing procedure has been established for CRBM and it is difficult to determine how realistic these curing conditions in the laboratory are.
It is known that the mechanical and performance properties of CRBM are intimately related to the curing condition [14], which is why several studies related to the curing process have been carried out to establish the most appropriate practice. Some of the conclusions of these studies have highlighted the importance of curing temperature and time, and how moisture loss is not the only mechanism involved in curing. It has been proved that curing specimens fully wrapped at 20°C for 28 days is an appropriately conservative practice to understand CRBM actual performance on site, where a surface course is typically applied a few days after construction of the base layer (CRBM mix) with trafficking commencing after a further few days [11]. This curing procedure will therefore be used in this study.

2.3. Asphalt pavements in airfields

Asphalt is widely used in airfield pavements, but in each section of an airfield (runway, taxiway, aprons, parking areas, etc.) different considerations apply. Commonly, asphalt is used in runways and taxiways in the surface, binder and base courses [15].
Defence infrastructure organisation (DIO) specifications for CRBM are available for the lower layers of taxiways and runways [16], but these materials use is limited due to unknown long term performance and risk of failure with high rehabilitation cost and traffic delay. In this case, CRBM mixes would be substituting an Asphalt Concrete (AC) base [17]. When using CRBMs, as there is no airfield design guide available, the current practice is to conservatively equate them to AC and this is why in this paper a CRBM mix has been compared to this type of material, to assess if this practice is accurate or can be improved.
There are a several widely used design guides for airfield pavement design, some examples being:

- DMG27 [17] – a UK design guide where separate design charts are plotted for different type of materials. These charts are based on resistance to permanent deformation, water sensitivity, durability, stiffness, resistance to fatigue and tensile strength. The inputs in this case are: traffic, type of subgrade and type of material.
- DIO[16] – lays down specification requirements for airfield pavement works using recycled bound materials, but no design guidance is included in terms of layer thickness.
- BAA[18] – design guide based also in graphs where the inputs are traffic, subgrade category and failure criteria. This guide is based on the California bearing ratio method with some analytical equations but no CRBM are included.
- FAArfield – airfield design software from the Federal Aviation Administration in the USA where the inputs are: traffic, design life, layer thickness, type of material (standard hot mixes) and stiffnesses. This software is based on failure by fatigue models, making iterative calculations to meet the design life selected.

The problem with these guides is that only the inputs can be changed, not the parameters used for the main calculations such as fatigue or permanent deformation. This is why a laboratory plan has been devised to obtain the characteristics mentioned for both mixtures (CRBM and HDM 50) and the results compared to see if a design for a hot mix can be applied for a CRBM mix.

3. LABORATORY PLAN

To undertake this investigation a CRBM mixture (foamed asphalt) was characterized completely in the laboratory while hot mix data were obtained from a previous study carried out in the same laboratory [19]. The materials and testing are described as follows.

3.1. Materials

For the CRBM mixture manufacture, the following materials were used:

- 0-10mm and 10-20mm RAP
- Fly Ash and Cement
- Bitumen penetration grade 100/150
- Water

The hot mix AC base was a HDM 50 [19]:

- Virgin aggregate (granite): 31.5mm, 20mm, 10mm and fines
- Filler (limestone)
- Bitumen penetration grade 40/60

3.2. Raw material characterization

The first step was to characterize the materials used in the investigation. With this objective the following tests were undertaken:

- RAP and hot mix aggregates combined mixture grading [20]

The gradations used are presented in Table 1 and Table 2.

Table 1: RAP grading

Sieve size (mm)	% Passing	Specification (min. - max.)	
31.5	100	86	100
20	100	65	100
14	100	53	90
10	88	47	77
4	6	30	55
2	0.3	22	41
0.5	0.2	10	27
0.25	0.1	8	25
0.063	0	6	20

Table 2: Hot mix aggregates grading

Sieve size (mm)	% Passing	Specification (min. - max.)	
40	100	100	100
31.5	100	90	100
20	88	71	95
6.3	55.1	44	66
2	29.4	20	40
0.25	12.5	6	20
0.063	7.1	7	11

- Bitumens characterization: penetration grade [21] and softening point [22].

Bitumen results are shown in Table 3.

Table 3: Bitumens characteristics

Binder	Penetration grade (tenths of mm)	Softening point (°C)	Purpose
40/60	47	72.1	HDM50
100/150	107	44.2	CRBM mix

3.3. Manufacture of CRBM mix specimens

3.3.1 Mix design

The mix design was selected to mirror material being manufactured at the airfield from which the RAP was obtained. At this airport, rehabilitation and reprofiling was needed and a study on CRBM mix design with foamed bitumen had been carried out. During this study an optimum mix design was developed and this was selected for this investigation, as it is a real case and it will be useful to compare laboratory results and results on site in the future.

In Table 4 and Table 5 the mix design of the CRBM used is presented. As can be appreciated in Table 1, the RAP contains less fines than the specification demands, so fly ash was added to correct the gradation. The final mix design grading is presented in Table 6 and both mix gradings are compared in Figure 2.

Table 4: Aggregates for CRBM mix

Aggregates	Proportion by mass (%)
0-10mm RAP planings	48.1
10-20 mm RAP planings	43.2
Fly ash	6.9
Cement	1.8

Table 5: CRBM mix design

Ingredient	Proportion by mass (%)
Aggregates	90.5
Foamed bitumen	3
Total water content	6.5

Table 6: CRBM mix final grading

Sieve size (mm)	% Passing	Specification	
		(min. -	max.)
31.5	100	86	100
20	97.4	65	100
14	85	53	90
10	72	47	77
6.3	56	38	64
4	41.8	30	55
2	28.7	22	41
0.5	14.6	10	27
0.25	11	8	25
0.063	8	6	20

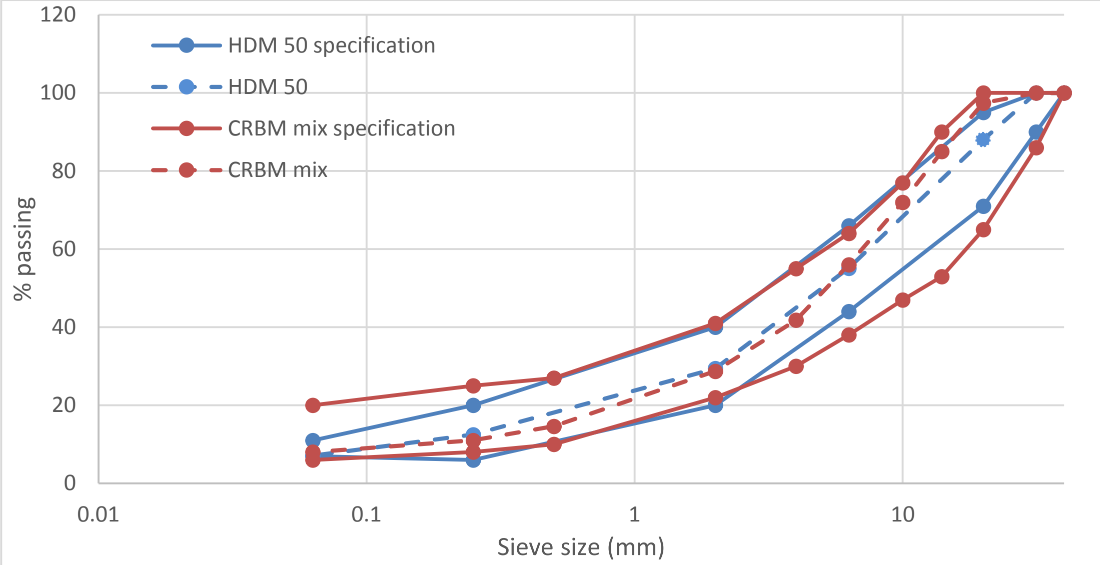

Figure 2: CRBM mix vs hot mix aggregates grading

3.3.2. Foaming

Foamed bitumen was produced in the laboratory using a mobile foaming plant type Wirtgen WLB 10 as shown in Figure 3. The foaming conditions are presented in Table 7. The half-life of the bitumen was measured using a Wirtgen measurement instrument (dipstick), and the results show a half-life greater than the recommended value of 6 seconds [23].

Before starting the Wirtgen WLB 10, all the components needed for manufacturing the samples had to be batched to comply with the mix design specified in Table 4 and Table 5. The bitumen needed to be heated at the set temperature (170°C) between 3 and 5 hours before using the equipment.

Once the materials were ready and the parameters set in the equipment, foam mix batches could be manufactured using a mixer coupled to the foaming plant, to avoid losing material. The aggregates had to be mixed with the water for 1 minute before adding the foam, and then another 3 minutes with the foam.

Table 7. Foaming conditions

Water Pressure	4 bar
Air pressure	5 bar
Bitumen type	100/150
Bitumen temperature	170°C
Water addition	1%

Figure 3. Wirtgen WLB 10

3.3.3. Compaction of foam mix specimens

Specimens were compacted using a Coopers Gyratory Compactor in accordance with BS EN 12697-31 [24], at a constant pressure of 600kPa, a speed of 30rpm and a gyration angle of 1.25º. The calculated amount of mixture was placed in the mould and compacted to a target void content of 5%. This resulted in cylinders with a diameter of 100mm and 60mm high. Specimens were de-moulded after 24h and placed for curing.

3.3.4. Specimen curing

For curing, test specimens were double wrapped in cling-film plastic using two separate sheets, as shown in Figure 4. Once wrapped, the specimens were stored in air at 20°C for 28 days. This curing procedure is a conservative approximation to simulate actual performance of CRBM on site [11], [16].
After this period all specimens were unwrapped, characterized and tested as described in section 3.5. In Figure 5 the specimens after curing are shown.

Figure 4: Double wrapped specimens

Figure 5: Cured specimens

3.4. Hot mix specimen manufacture

The process for hot mix sample manufacturing comprised [19]:

- Perform Particle Size Distributions on the virgin aggregates.
- Perform Penetration Tests on the bitumen.
- Perform Softening Point Tests on the bitumen.
- Create an Aggregate Blend to fit within the specification envelope, as shown in Figure 2.
- Use prior knowledge of the aggregates and bitumen to estimate the Binder Content (4-2%).
- Perform Maximum Density Tests on trial mixes to confirm that the targeted volumetrics can be achieved.
- Create a Mixture Composition based on the above.
- Manufacture slabs using a Laboratory Roller Compactor.
- Core 100mm and 200mm diameter specimens using a diamond tipped asphalt coring rig.

3.4.1. Mix design

The mix design selected to achieve the desired air void content is presented in Table 8.

Table 8: HDM 50 mix design

Constituents	Proportion by mass (%)
31.5 mm agg.	10.5
20 mm agg.	19.2
10 mm agg.	19.2
Crushed rock fines	43.1
Filler	3.8
Bitumen	4.2

3.5. Testing methodology

After the materials had been characterised, and the specimens manufactured and cured (CRBM), the following tests were carried out.

- Bulk density BS EN 12697-6:2012, procedure C [25], max density to BS 12697-5:2009, method A [26] and air voids to BS EN 12697-8:2003 [27].
- Determination of indirect tensile stiffness modulus (ITSM) to BS EN 12697-26:2004 Annex C, to assess the load spreading ability and durability after wet conditioning, immersed at 20°C for 24 hours (immediately following the curing period).
- Resistance to permanent deformation under dynamic loading was assessed by repeated load axial test without confinement (RLAT) to BS DD 226.
- Determination of the indirect tensile strength (ITS) to BS EN 12697-23:2003 before and after wet conditioning.
- Determination of indirect tensile fatigue (ITF) [28]. Fatigue performance of a material is one of the key parameters used to assess a pavement's expected life. The fatigue test was undertaken under several stress conditions, with the number of loading cycles to failure recorded. This enabled a 'fatigue life' to be calculated and plotted.

4. LABORATORY RESULTS: COMPARISON BETWEEN MATERIALS

CRBM test results obtained in the laboratory are presented below and compared to DMB 50 test results obtained by E. Draper [19].

4.1. Mixture volumetrics

Table 9: Mixture volumetrics

Mixture	Bulk density (Kg/m^3)	Max density (Kg/m^3)	Air voids (%)
CRBM	2146	2515	15
HDM50	2442	2551	4.3

4.2. Stiffness

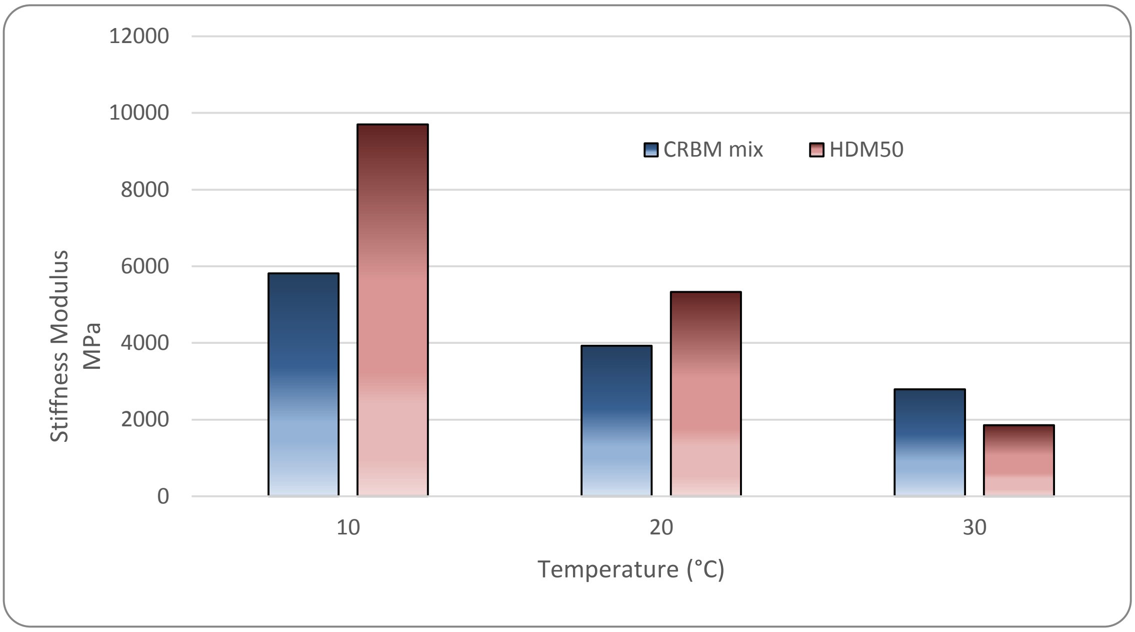

Figure 6: Average stiffness values

4.3. Strength

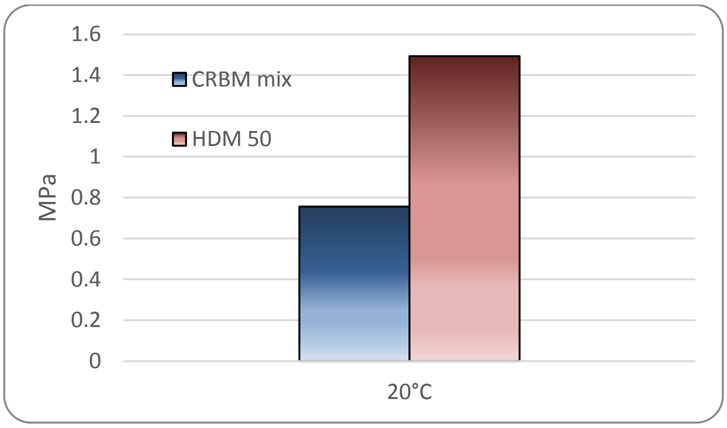

Figure 7: Average strength values

4.4. Durability

Table 10: Moisture sensitivity

Mixture	Retained stiffness (%)	Retained strength (%)
CRBM	120	92
HDM50	92	NA

4.5. Resistance to permanent deformation

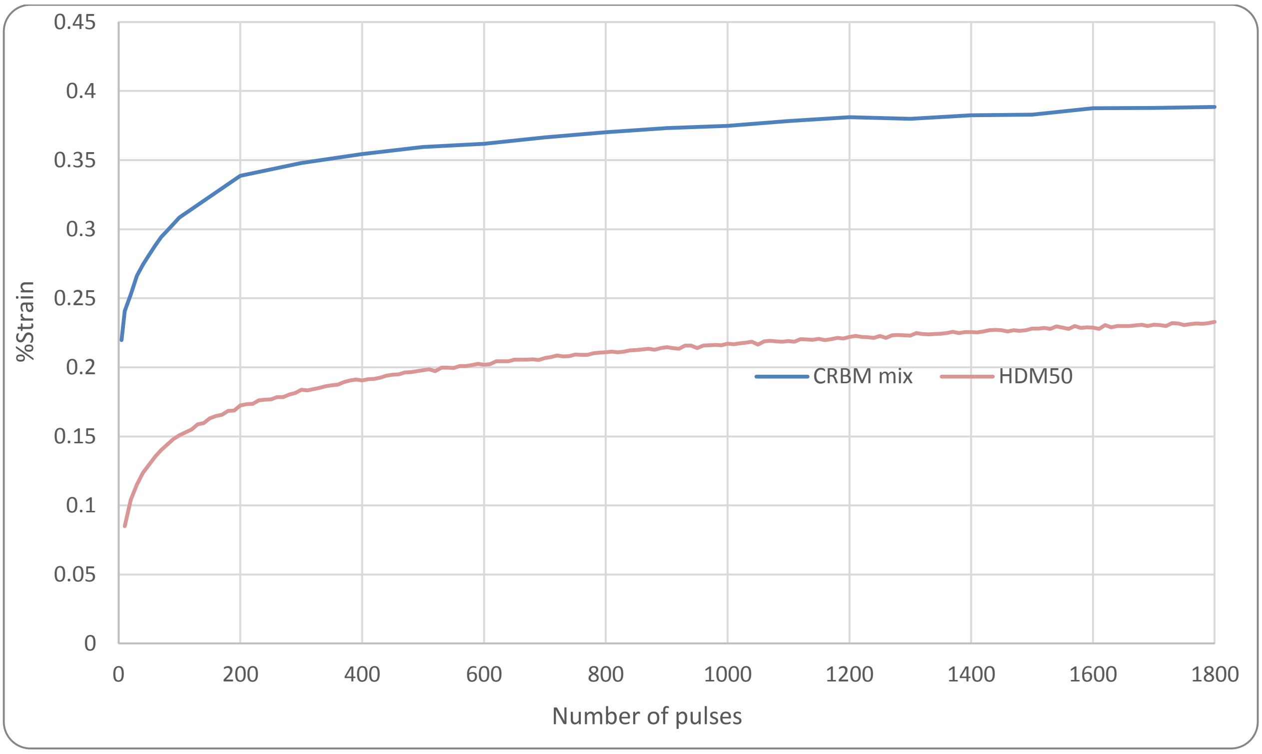

Figure 8: Permanent deformation

4.6. Fatigue

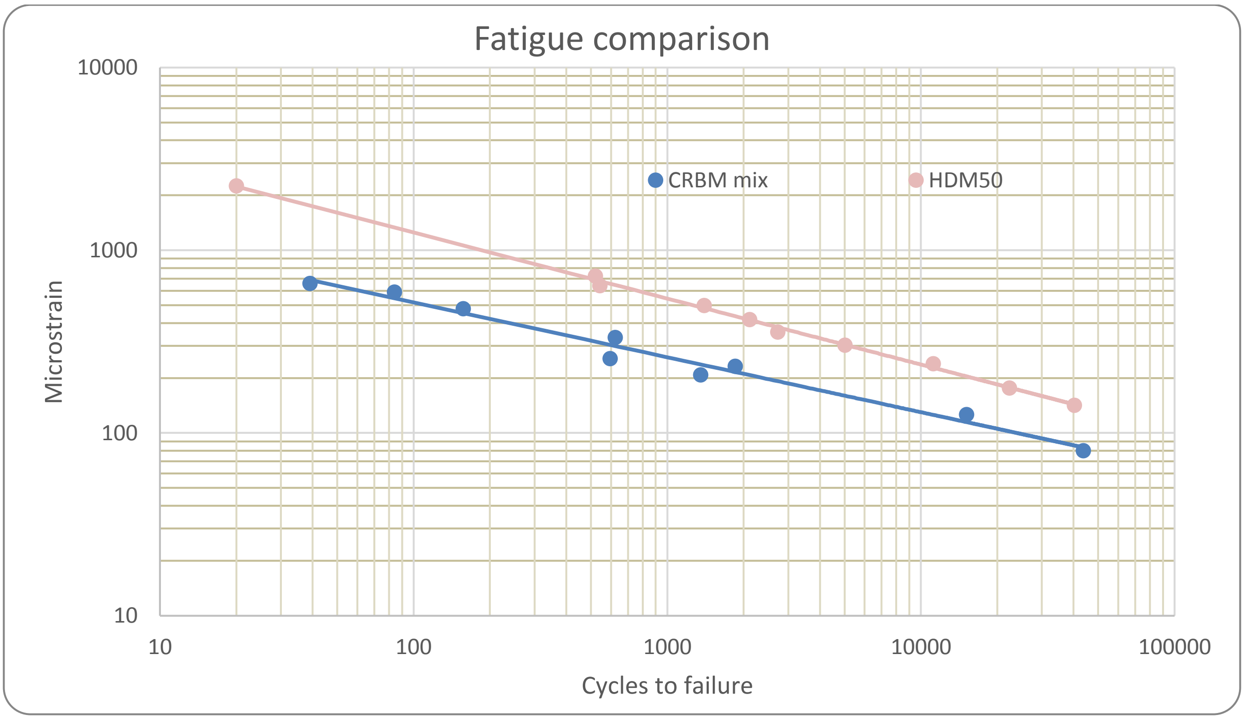

Figure 9: Fatigue characteristics

4.7. Results discussion

It can be appreciated that there are differences in all the results obtained between hot mix asphalt and the CRBM. As expected the performance of the CRBM mix is not as good as the hot mix in some aspects, despite it being within specification limits [16].
Particular mention should be made of the air void content of the CRBM shown in Table 9. The value obtained in the laboratory (15%) is very high compared with the target (5%) but similar to other foam mix studies [29]. Inspection of a broken specimen in Figure 10, reveals that these voids are not readily apparent. It may therefore be concluded that they are in the form of 'micro-voids' within the binder-filler-fines mortar.

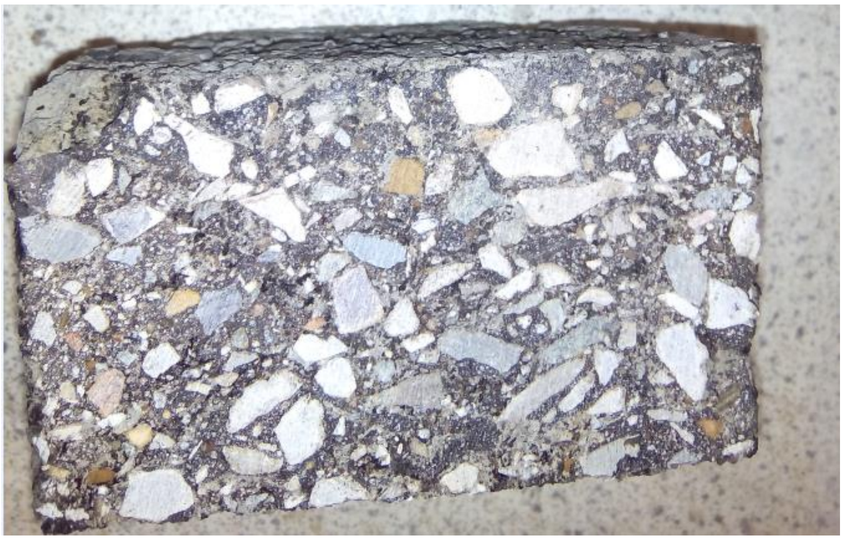

Figure 10: CRBM broken specimen

Figure 6 shows that the CRBM mixture was less temperature susceptible than HDM 50, behaving more consistently in terms of stiffness. This is likely to be due to the action of cement within the mixture. Regarding the stiffness value used for design (at 20°C), it can be noticed that the difference between the two mixtures is moderate (4000MPa vs 5300MPa) if it is taken into account that the HDM50 evaluated has an average stiffness value, being possible to find HDM50 with lower stiffness and still be within specifications.
Strength and stiffness results after wet conditioning were obtained to assess mixture durability, see Table 10. It could be considered surprising that CRBM stiffness after 7 days soaking is greater than before, obtaining a retained stiffness greater than 100%, but this is likely to be due to the content of cement, which was still active and used the moisture to gain strength, making the specimens stiffer than before. However, these results show that both mixtures have good durability properties.
In terms of permanent deformation, in Figure 8, both mixtures have much better rut resistance than the UK highways requirements (below 2% strain [5]), and high rut resistance in very heavily stressed sites is an important characteristic, therefore important for airfield pavements.
Finally, the fatigue results in Figure 9 show a difference amounting to a factor of about four at 100 microstrain (typical highway strain levels), rising to about eight at 400 microstrain (more typical of airfields).

5. CONCLUSIONS

With the results obtained from the laboratory investigation it is concluded that CRBM mixes have acceptable properties for use in airfield pavements. Resistance to permanent deformation, fatigue, temperature susceptibility and durability results show that these materials give reasonable performance but differ from conventional hot mixes. This means that, for the design approach with CRBM, actual design guides should be optimised and calibrated to include performance of CRBM.
As the current practice is to assume material equivalency with hot mix and it is not possible to include material characteristics other than stiffness and Poisson's ratio in these guides, the next step of the author's investigation will be to analyse some of the guides mentioned (DMG 27, FAArfield and BAA) against mechanistic/empirical software where fatigue and permanent deformation laws can be changed. Once the software is chosen, the first step will be to use hot mix performance to understand differences between methods and reproduce the design guides mentioned with the selected software. Then, pavements structures containing CRBM will be analysed with this software obtaining a design guidance. Finally, CRBM will be studied in terms of failure mechanisms, taking into account the curing process and the crack development in the mixture. The final objective will be to develop a new design methodology and guidance for using CRBM in airfield pavements.

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