# Successful demonstration of lower temperature asphalt on the UK strategic road network

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Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.131

## ABSTRACT

*Lower temperature asphalts (LTAs) have been identified as a way of reducing both the energy required to produce and lay asphalt materials and the nuisance of fumes for workers. The use of LTAs has not yet reached its full potential in the United Kingdom. To encourage uptake in appropriate applications and inform the national specifications, a project was undertaken to demonstrate use of a LTA on the strategic road network. The project was realised as a result of successful collaboration between the national road authority, industry and a research organisation.*

*A site with sections of LTA surface and binder course mixtures produced using an 'injection foaming' technology was laid and monitored for initial properties. Sections of conventional hot mix materials were also laid and monitored to enable direct comparison. Visual inspection, temperature measurement and thermographic imaging were undertaken at regular intervals throughout construction. Physical properties of the materials used were established through laboratory testing of samples taken at site and the carbon footprint of construction was evaluated. Overall, the demonstration proved that effective application of an LTA technology could be achieved but also yielded some important practical messages for the future application of LTAs.*

**Keywords:** Carbon, Health Safety and Environment, Reclaimed asphalt pavement (RAP) Recycling, Strategic Highway Research Program, Warm Asphalt Mixture

# 1 INTRODUCTION

One of the key observations from the Eurasphalt & Eurobitume congress of 2012 was the low rate of uptake of lower-temperature asphalt materials compared *inter alia* to North America, where a good level of implementation of these materials has already been achieved [1]. With this in mind, a project was embarked on in the UK to demonstrate the potential viability of lower temperature asphalt materials (LTAs) on the UK's strategic road network (SRN; [2]). TRL set out to impartially observe a live demonstration of lower temperature asphalt material being laid, along with a conventional hot mix asphalt (HMA) reference material to provide a direct comparison. The demonstration provided an opportunity to observe construction from start to finish and to record material property data, take samples, record observations throughout the construction and monitor early-life performance.

# 2 SCOPE OF WORKS AT DEMONSTRATION SITE

## 2.1 Site

The demonstration site was located within a 1.1 km maintenance scheme on the A5 between Grendon and Mancetter. A section of the westbound carriageway, approximately 220 m in length, was inlaid with 110 m of LTA and 110 m of conventional HMA, and is shown in Figure 1. Production, laying and compaction were closely monitored, and materials were sampled and subjected to extensive laboratory testing. The results of this testing, which followed a protocol agreed prior to the site trial, have been made available [3] and have been used in this report. Annual energy consumption data [4] was made available to allow the carbon footprint of the materials to be calculated.

The works described took place on the morning of 18th January 2014. The ambient temperature was 4 °C when laying commenced at 00:20, it cooled slightly to reach a low of 3 °C at 01:30 and then steadily rose again to reach 5 °C at 02:40 and 6 °C at 04:15 when the road was reopened to traffic. The weather was largely dry throughout the laying operation although light rain fell from 03:10 until well beyond the point when the site was reopened to traffic at 04:15.

**Figure 1: Location of the demonstration site within the A5 Grendon to Mancetter maintenance scheme**

## 2.2 Asphalt mixtures

The mixtures used for the site were asphalt concretes complying with BS EN 13108-1 [5] in categories AC 20 HDM bin 40/60 design for the binder course and AC 14 surf PMB PSV 65 for the surface course (where PMB = polymer modified bitumen; PSV = polished stone value). The HMA mixtures were manufactured conventionally and the LTA mixtures using a patented 'injection foaming' LTA technique. This technique involves injecting a small, controlled amount of water into hot bitumen via foaming nozzles, immediately prior to coating the aggregate. This results in a large but temporary increase in the effective volume of binder which facilitates coating at lower temperatures [6]. The target binder content of both binder course mixtures was 4.3 % and the target binder content of both surface course mixtures was 5.1 %. The mixtures were as follows:

| | | | |
|---|---|---|---|
| • Mixture 1 | LTA | Binder course | AC 20 HDM bin 40/60 design |
| • Mixture 2 | LTA | Surface course | AC 14 surf PMB PSV 65 |
| • Mixture 3 | HMA | Binder course | AC 20 HDM bin 40/60 design |
| • Mixture 4 | HMA | Surface course | AC 14 surf PMB PSV 65 |

The mean production temperatures and maximum and minimum batch temperatures are presented in Table 1. Differences in production temperatures between the lower temperature and hot materials were approximately 80 °C for the binder course mixtures and 60 °C for the surface course mixtures.

**Table 1: Production temperatures**

| Mixture No. | Type | Course | Mixing temperature (°C) | |
|---|---|---|---|---|
| | | | **Mean** | **Range** |
| 1 | LTA | Binder | 92 | 7 (88 – 95) |
| 2 | LTA | Surface | 107 | 27 (92 – 119) |
| 3 | HMA | Binder | 171 | 33 (149 – 182) |
| 4 | HMA | Surface | 169 | 41 (141 – 182) |

Various proportions of reclaimed asphalt (RA) were also incorporated into the mixtures as shown in Table 2. The amount of RA in both LTA and HMA surface course mixtures was equivalent and facilitated direct comparison. Equivalent proportions could not be achieved in the binder course mixtures, this was thought to be due to a combination of the higher fines content of the binder course HMA material (relative to the HMA surface course material) and high moisture content of the feedstock RA, which would have required superheating of the aggregate (to dry the RA) to temperatures beyond acceptable production plant tolerances; as a result the proportion of RA in the binder course HMA had to be reduced to 5.9 %.

**Table 2: Reclaimed asphalt contents**

| Mixture No. | Type | Course | Reclaimed asphalt (%) | |
|---|---|---|---|---|
| | | | **Mean** | **Range** |
| 1 | LTA | Binder | 25.9 | 2.8 (24.4 – 27.2) |
| 2 | LTA | Surface | 15.6 | 2.2 (14.9 – 17.1) |
| 3 | HMA | Binder | 5.9 | 13.0 (0.0 – 13.0) |
| 4 | HMA | Surface | 15.6 | 1.2 (15.2 – 16.4) |

## 3 MATERIAL PROPERTIES AT PLANT AND SITE

### 3.1 Delivery and rolling temperatures

The mean material temperatures at delivery (laid) and during rolling are given in Table 3. The HMA delivery and rolling temperatures were between 85 °C and 90 °C higher than for the LTA mixtures.

**Table 3: Mean material temperatures (delivery and rolling)**

| Mixture No. | Temperature | Course | Mean temperature (°C) | |
|---|---|---|---|---|
| | | | **Delivery** | **Rolling** |
| 1 | LTA | Binder | 80 | 70 |
| 2 | LTA | Surface | 85 | 65 |
| 3 | HMA | Binder | 170 | 155 |
| 4 | HMA | Surface | 170 | 155 |

### 3.2 In situ tests

In situ testing included an estimation of the in-situ air voids content of the binder course mixtures using a nuclear density gauge. Measurements were also made on the surface course for pavement longitudinal surface regularity. Texture depth was not measured due to the wet weather conditions after completion of the surface course. The mean, maximum and minimum values of in-situ air voids contents are presented in Table 4.

**Table 4: In-situ test results**

| Mixture No. | Mixture Type | Course | Air voids content (%) | | Longitudinal surface regularity |
|---|---|---|---|---|---|
| | | | **Mean** | **Range** | |
| 1 | LTA | Binder | 9.5 | 3.4 (7.4 – 10.8) | – |
| 2 | LTA | Surface | – | – | Complied |
| 3 | HMA | Binder | 7.6 | 2.1 (6.6 -8.7) | – |
| 4 | HMA | Surface | – | – | Complied |

It can be seen that in-situ air voids of both the LTA and HMA binder course mixtures were relatively high at >7 %. Furthermore, higher in-situ air voids contents were found in the LTA mixture than the HMA mixture. The surface regularity complied with the specification requirements as detailed in Series 700 Table 7/2 of the *Specification for Highway Works*, SHW [7], according to transverse straightedge measurements undertaken by and independent test house present on site. The construction of the LTA mixtures on the demonstration site proved no more difficult than that with the HMA mixtures.

The main difference, apart from the temperature, seems to be that the compaction of the LTA mixtures was more variable. Inadequate compaction can lead to higher voids, lower density and potentially lower stiffness. Results obtained from tests conducted on laboratory manufactured samples suggest LTA performance comparable with that of HMA is achievable.

## 4 LABORATORY TESTS OF MATERIAL PROPERTIES

### 4.1 Compositional analysis

Compositional analysis was carried out for a single sample of each mixture with binder content determined using the ignition method in accordance with BS EN 12697-39 [8]. All the mixtures complied with the producer's Declaration of Performance (DoP) in terms of grading and binder content.

### 4.2 Recovered binder properties

Samples of binder from the two binder course mixtures were recovered by rotary evaporator to BS EN 12697-3 [9] and analysed for the binder properties of penetration to BS EN 1426 [10] and softening point to BS EN 1427 [11]. The results are presented in Table 5.

**Table 5: Recovered binder properties**

| Mixture | Mixture Type | Course | Penetration (0.1 mm) | Softening Point (°C) |
|---|---|---|---|---|
| Mixture 1 | LTA | Binder | 28 | 60.2 |
| Mixture 3 | HMA | Binder | 22 | 64.2 |

Although the results are based on a single sample and are therefore too limited for a definitive conclusion, the values appear to support the hypothesis that the lower heating in the LTA results in less initial binder hardening with higher measured recovered penetrations and lower recovered softening points. However, the differing proportions of RA in the two mixtures, the recovery method and the repeatability of the penetration and softening point tests should all be considered before drawing any definitive conclusions.

### 4.3 Density and air voids content

The maximum densities of the mixtures were first determined in accordance with BS EN 12697-5 [12] using Method A, volumetric. Six cylindrical specimens were cored from laboratory-manufactured slabs (bulk samples were taken on site and used to manufacture the slabs in the laboratory, using a reheating temperature of 130 °C for both HMA and LTA) and then used for the determination of the bulk density in accordance with BS EN 12697-6 [13] three times using Procedure A, dry, Procedure C, sealed, and Procedure D, dimensions. The air voids contents were determined according to BS EN 12697-8 [14] and the mean values are shown in Figure 2.

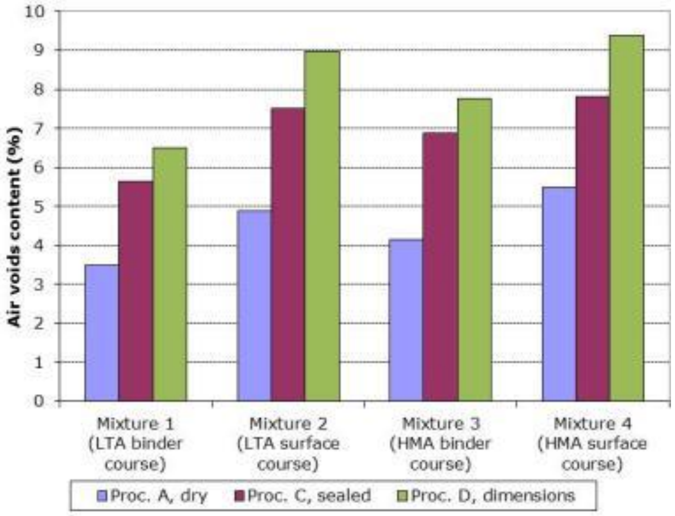

**Figure 2: Air voids content of laboratory compacted specimens**

Figure 2 shows that the air voids content depends on the procedure used for the determination of the bulk density. For a given method, similar air voids contents were obtained for the LTA and HMA mixtures, although for LTA materials the reheating procedure in the laboratory is the same as for the HMA as there is no longer the workability present from the original process. The LTA binder course material had significantly more RA compared to the HMA binder course which could lead to greater variability in the density of the material as the specific gravity of the aggregate(s) within the RA added may be different and more variable than the virgin material. Higher air voids contents were found for the surface course mixtures compared to the binder course materials. This would be expected as thin surface course materials tend to be more open to provide the required level of texture.

## 4.4 Water sensitivity

Resistance to moisture damage was evaluated by means of the water sensitivity test in accordance with BS EN 12697-12 [15] using Method A for the indirect tensile stiffness ratio, *ITSR*. Each specimen was tested for indirect tensile strength at 20 °C, with the results presented in Figure 3.

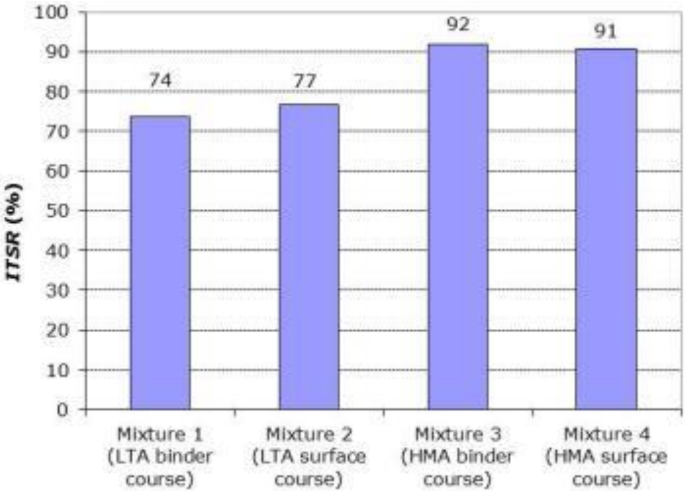

**Figure 3: Water sensitivity test results at 20 °C**

Figure 3 shows that the ITSR values for all the mixtures were above the specified level of 70 %, indicating adequate resistance to water damage. Furthermore, the ITSR value for both binder course mixtures was lower than that of the equivalent HMA mixture, possibly as a result of the increased amount of RA in the mixture. A possible explanation is that the higher air voids contents of the LTA mixtures measured from site samples (Table 4) allow more water to enter the asphalt during the conditioning.

### 4.5 Permanent deformation

### 4.5.1 Cyclic compression

The resistance to permanent deformation was evaluated using the triaxial cyclic compression test in accordance with BS EN 12697-25 [16] to Method B. The test conditions were as defined in BS EN 13108-20 [17] for AC binder course and AC surface course mixtures. The results are shown in Figure 4 for Mixture 1 (LTA binder course) and in Figure 5 for Mixture 3 (HMA binder course). Creep rates are calculated by fitting a straight line through the linear part of the creep curve.

The results show low creep rates for the two mixtures, indicating good resistance to permanent deformation. Furthermore, the LTA mixture had, on average, lower creep rates than the HMA mixture, indicating potential superior resistance to permanent deformation. However, higher variability was observed from the LTA mixture. Based on these results, Mixture 1 (LTA binder course) complies with the category $f_{c\ \max\ 0,4}$ whereas Mixture 3 (HMA binder course) complies with the category $f_{c\ \max\ 0,6}$, where the categories are defined in BS EN 13108-1 [5].

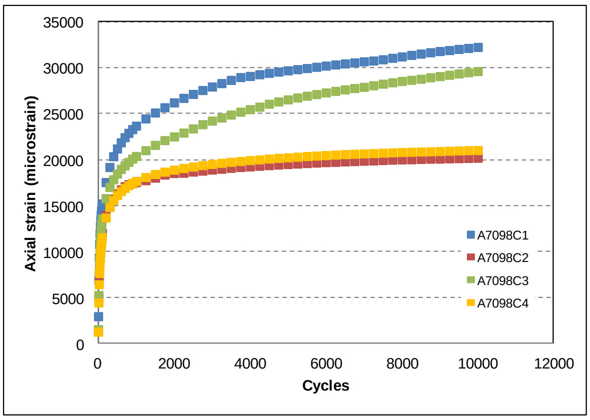

**Figure 4: Creep curves for Mixture 1 (LTA binder course)**

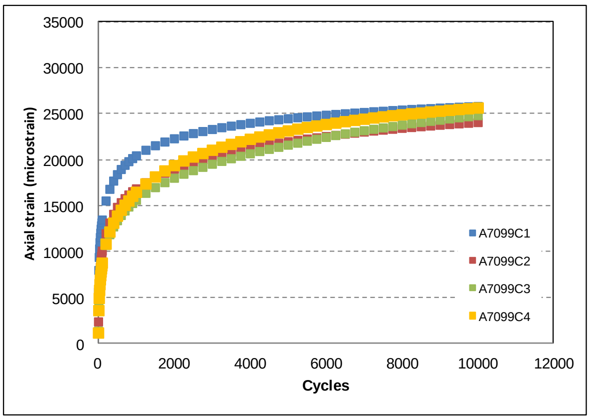

**Figure 5: Creep curves for Mixture 3 (HMA binder course)**

### 4.5.2 Wheel tracking

The resistance to permanent deformation was also evaluated using wheel-tracking in accordance with BS EN 12697-22 [18] using both the large-size device and the small-size device to Procedure A.

- For testing with the large-size device, the samples were compacted in accordance with BS EN 12697-33 [19] using a single tyre pneumatic roller to the heavy compaction option. Only one replicate per mixture was used although the test normally requires two.
- For testing with the small-size to Procedure A, the samples were compacted in accordance with BS EN 12697-33 [19] using a smooth steel roller. Procedure A is normally only used for hot rolled asphalt mixtures and only two replicates per mixture were tested although the test normally requires six.

The results are shown in Figure 6 and Figure 7 for the large and small size test devices, respectively.

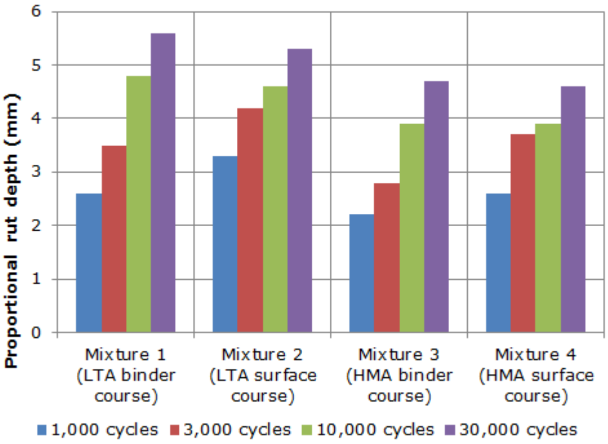

**Figure 6: Wheel-tracking results for large size device**

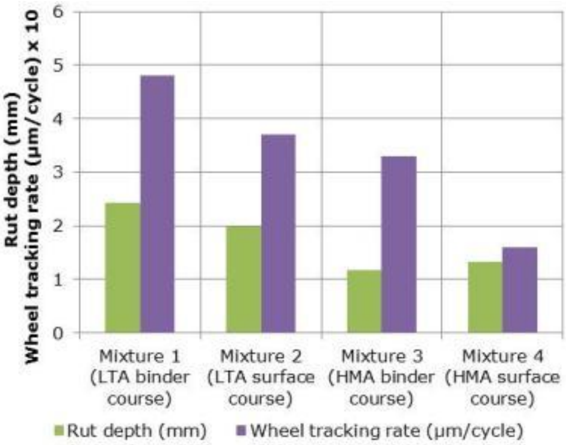

**Figure 7: Wheel-tracking results for small size device to Procedure A**

The results indicate superior performance for the HMA mixtures, however, all results fall within the limits specified in the UK guidance document on the use of EN 13108 [20].

## 4.6 Stiffness

### 4.6.1 Indirect tension stiffness test

Stiffness modulus was determined in accordance with BS EN 12697-26 [21] using Annex C for applying indirect tension to cylindrical specimens (IT-CY), with test conditions as specified in BS EN 13108-20 [11]. Samples were taken from site and prepared in the laboratory. The mean stiffness values are shown in Figure 8.

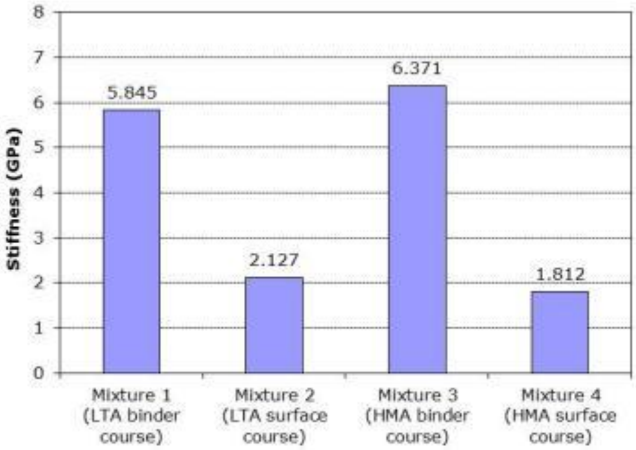

Figure 8: Stiffness modulus (IT-CY)

The results show similar stiffness values for the LTA and HMA binder course. It could be argued that there is less binder ageing for the LTA mixtures, as a result of the mixing process, and therefore the stiffness values could be expected to be lower as a result. However, small variations that are observed are fairly typical for any material subjected to stiffness testing. The results also show comparable stiffness values for the LTA and HMA surface course.

### 4.6.2 Four point bending stiffness test

Stiffness modulus was also determined in accordance with BS EN 12697-26 [21] using Annex B for four point bending on prismatic specimens (4PB-PR). BS EN 13108-20 [17] gave the test conditions Figure 9, Figure 10, and Figure 11 show the mean stiffness values at different temperatures and frequencies.

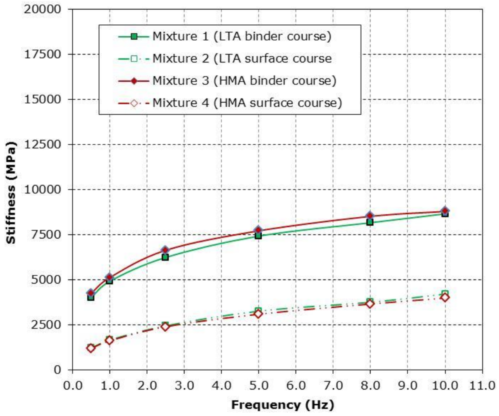

Figure 9: 4PB stiffness test results at 20 °C

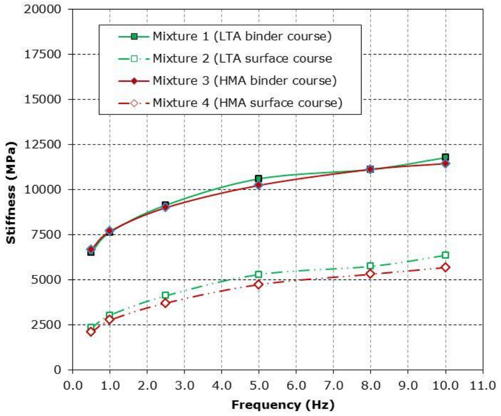

Figure 10: 4PB stiffness test results at 15 °C

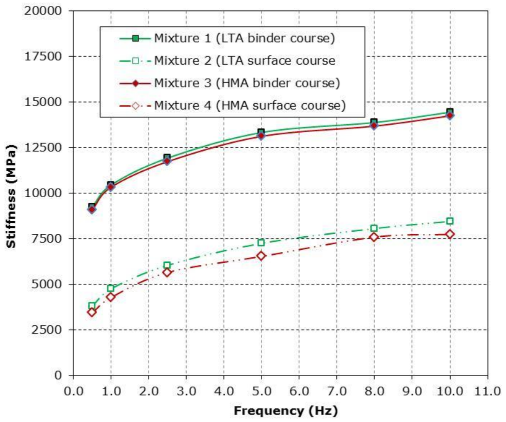

**Figure 11: 4PB stiffness test results at 10 °C**

The stiffness increased as the temperature decreased and as the frequency of loading increased. The binder courses are much stiffer than the surface course mixtures; however, the differences between the stiffness values of the LTA and HMA were small, with the values of the LTA binder course mixture being slightly lower than that of the equivalent HMA mixture whilst the reverse was the case for the surface course mixtures.

## 4.7 Fatigue resistance

The fatigue resistance was determined in accordance with BS EN 12697-24 [22] using Annex D for the four-point bending test on prismatic shaped specimens and test conditions as given in BS EN 13108-20 [11]. The relationships between the strain (ε) and the number of cycles to failure ($N_{50}$), defined as the number of cycles to 50 % stiffness reduction, are plotted in Figure 12. It should be noted that a limited number of specimens were available for testing and these results should therefore be treated as 'exploratory'. The coefficients for the power trend line and the fatigue resistance in terms of microstrain at $10^6$ cycles, $\varepsilon_6$, are given in Table 7.

**Table 7: Resistance to fatigue at $10^6$ cycles**

| Mixture | Mixture Type | Course | Trend line | | | ε6 (microstrain) |
|---|---|---|---|---|---|---|
| | | | Constant | Power | $R^2$ | |
| Mixture 1 | LTA | Binder | $5.42 \times 10^{19}$ | 0.691 | 86.8 | 103 |
| Mixture 2 | LTA | Surface | $5.16 \times 10^{11}$ | 3.20 | 85.5 | 113 |
| Mixture 3 | HMA | Binder | $1.66 \times 10^{14}$ | 4.00 | 99.6 | 69 |
| Mixture 4 | HMA | Surface | $4.32 \times 10^{14}$ | 4.17 | 94.8 | 119 |

The higher the $\varepsilon_6$ value, the better the resistance to fatigue. The results indicate better fatigue resistance for the LTA binder course mixture than the HMA one whilst the difference between the LTA and HMA surface course mixtures was minimal. Due to the differing proportions of RA in the mixtures it is not possible to draw any definitive conclusions about resistance to fatigue.

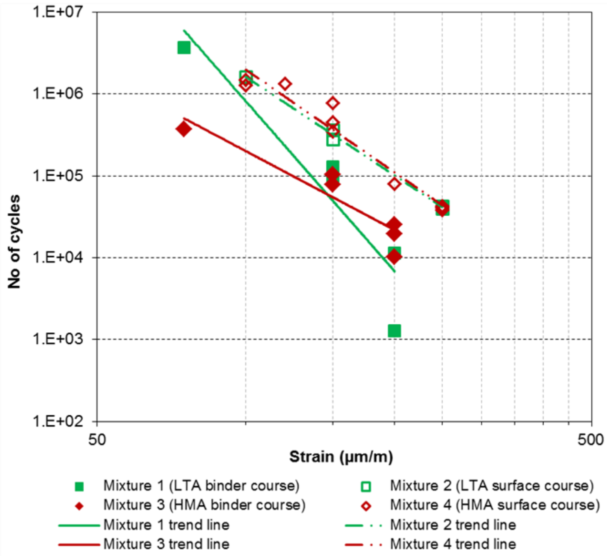

**Figure 12: Laboratory fatigue results**

## 5 CARBON FOOTPRINT

One of the principal benefits of the LTA technologies is the energy savings that can be realised via lower temperature mixing. Table 1 indicates the material temperatures recorded at the weighbridge and this shows that the LTA mixtures used at the demonstration site fall into the HWMA category [23]. The HMA surface and binder both fall comfortably within the HMA classification. The contribution to climate change of the mixtures used has been analysed using the life cycle based approach of asPECT (the asphalt Pavement Embodied Carbon Tool; [24]).

The cradle-to-gate (raw material extraction through to the end of asphalt production), cradle-to-site (raw material production through to installation at site) and total $CO_2e$ footprints were calculated for the works carried out at the demonstration site and are presented in Table 9.

**Table 9: Calculated $CO_2e$ footprints for the four mixtures used**

| Component | LTA binder course | LTA surface course | HMA binder course | HMA surface course |
|---|---|---|---|---|
| Cradle-to-gate $CO_2e$ footprint ($kgCO_2e$ per t) | 27.65 | 38.93 | 35.24 | 45.21 |
| Cradle-to-site $CO_2e$ footprint ($kgCO_2e$ per t) | 42.61 | 53.89 | 50.20 | 60.17 |
| Total $CO_2e$ footprint ($kgCO_2e$) | 2511 | 2441 | 3513 | 3578 |

Clear savings are observed for the LTA mixtures relative to the corresponding HMA mixtures. Based on the cradle-to-gate footprints, the saving is 14 % for the surface course mixtures and 22 % for the binder course mixtures. It should be noted that only the surface course mixtures have similar RA contents, therefore the former figure is more representative. The total $CO_2e$ footprint for the works is calculated at 12.0 tonnes. If all 233.68 t of materials used on the works were LTA then the total footprint would have been 11.1 t $CO_2e$, relative to 12.8 t for all HMA, a saving of 1.6 t $CO_2e$.

$CO_2e$ savings derived from both energy savings at the plant (the lower heating and drying energy of the LTA asphalt mixtures) and the recycled content that was incorporated. Direct comparisons were possible for the surface course materials which both had a recycled content of 15.6 %; in relation to these mixtures a saving of 13 % could be attributed to lower plant energy consumption and a further 5 % saving due to the recycled content. This demonstrates the importance of pursuing both recycling and LTA technologies. In particular, LTA technologies which do not have to overcome the latent heat of vaporisation during heating may realise considerable benefits compared to those mixed above 100 °C. In the latter instance, increasing RA content will realise a greater yield in terms of overall benefit. To maximise energy efficiency during production of asphalt, operations should be carefully planned to avoid repeatedly switching between hot and lower-temperature mixtures.

# 6 CONCLUSIONS

The demonstration site on the A5 Grendon has confirmed previous experience on other sites that the production and application of both LTA and HMA mixtures are similar and can be achieved in practice with the right amount of care and checking procedures in place.

The following conclusions were drawn from the demonstration site:

- The LTA could be laid successfully provided appropriate care was taken. There were similar comments from operatives about both LTA and HMA mixtures.
- LTA mixtures appear to require a higher level of control to ensure that adequate compaction is achieved.
- An increased proportion of reclaimed asphalt was successfully employed in the mixtures at lower target mixing temperatures.
- The carbon footprint calculation using asPECT v4.0 indicates a cradle-to-gate CO2e saving in the region of 13-16 % associated with the use of LTA materials over their conventional HMA alternatives, which can purely be attributed to energy savings at the mixing plant. The works in total at Grendon on the night of the trial saved 0.7 tCO2e by replacing approximately half of the conventional HMA with LTA alternatives. If LTAs had replaced all conventional materials used then the saving would have been in the region of 1.6 tCO2e.

Testing of laboratory prepared samples of both LTA and HMA materials gave comparable properties for compactibility, deformation resistance and stiffness. Water sensitivity testing indicated slightly higher susceptibility of LTA. However, samples taken from sites where the material had been laid previously has shown a large variation in air voids content, and hence stiffness, for the LTA materials. Similarly, the in situ density measurements on the binder course layer on the demonstration site showed greater variability in the LTA compared with the conventional HMA. This would seem to indicate that stricter quality control procedures may be needed on site for LTA materials. The limited amount of data gathered with regard to fatigue meant that meaningful conclusions could not be drawn.

Overall, the monitoring of sites supports the use of LTA mixtures in routine construction and maintenance of road pavements with appropriate quality control measures in place. As a result of the wide variation in technologies to produce LTA mixtures, and the additional care that may be required during installation, sites should be monitored to confirm that materials are suitable for routine use. It is also important to establish the criteria for their acceptance because these may differ from those for HMA and could also differ between various LTA technologies.

## ACKNOWLEDGEMENTS

TRL would like to thank the Highways Agency (now Highways England), the Mineral Products Association and the Refined Bitumen Association (now Eurobitume UK) for funding this research project. The full project report with detailed results has been published as TRL PPR742 [3].

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