

DESIGN AND CONSTRUCTION OF A ROAD PAVEMENT USING FLY-ASH IN HOT ROLLED ASPHALT

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ABSTRACT

Using fly ash to substitute the filler in bituminous mixtures is not only a way of disposing of this waste in a safe manner but it is a way of reducing the energy requirements for the preparation and placement of this composite in road pavements.

This paper describes briefly the background work carried out in the laboratories of CEMU to develop the mix design and to evaluate the reductions of energy requirements for the production of a bituminous mixture, i.e., hot rolled asphalt (HRA) which is used in the UK to surface motorways and heavily trafficked roads. Hot rolled asphalt is prepared in site plants heating the aggregates and bitumen at 160°C and is placed and compacted normally at not less than 125°C. Thus the energy requirements for the preparation, placement and compaction of HRA is very high. The HRA designed at CEMU is a low energy mix which contains fly ash. It can be prepared at a temperature of 125°C and placed and compacted at a temperature as low as 85°C. This mix was used for the construction of the overlay of a very heavily trafficked road, the A689 in the north of England.

The construction of the overlay for the pavement is described and the results of the in situ pavement are assessed with results obtained during four years of monitoring the performance of the section paved with the new low energy HRA.

The paper also discusses the design and development of a semiautomatic rut measuring device which was especially designed to monitor the performance of the pavement.

The environmental and cost implications of using fly ash in bituminous mixes is quantified using the results obtained during the laboratory design and construction of the trial HRA overlay.

INTRODUCTION

One of the most important requirements of bituminous mixtures is that their compaction characteristics in the laboratory can be repeated during construction in the field. Poor performance of bituminous mixtures in road pavements is in many cases attributed to poor mixing and inadequate compaction.

Mixes that can be mixed, handled and placed without difficulties are said to be workable. Workability is a parameter which indicates these attributes in a bituminous mix. Most bituminous mixes can be made workable if enough high temperature of compaction is maintained during the process, this is obtained by heating mineral aggregates, filler and bitumen to relatively high temperatures, and transporting and laying the mixes in short periods to avoid loss of temperature. Many mixes become unworkable when they reach temperatures of ± 120 °C.

The main objectives of the study reported in this paper were:

- To assess the effect of fly ash (FA) on the engineering and performance properties of hot rolled asphalt.
- To assess the influence of changes on the temperature of mixing and compaction in conventional and FA hot rolled asphalt.
- To validate any findings using a wide range of mineral aggregates and fillers.
- To conduct a full scale trial using one of the design mixes.

The project on the design of low energy hot rolled asphalt (LEHRA) using FA was supported by the Energy Efficiency Office of the Department of the Environment U.K., Cleveland County Council U.K., National Power U.K. and Tilcon North Limited U.K.

MATERIALS USED IN THE INVESTIGATION AND THEIR PROPERTIES

The materials used in the laboratory investigation were representative of those used in road pavement construction in the North of England. Four coarse aggregates, four sands, three limestone powders and four fly ashes were selected for the study. The code used to distinguish them are :

| | |
|-----------------------|---------------------|
| Coarse Aggregate (CA) | Sand (S) |
| Limestone Filler (L) | Fly Ash Filler (FA) |

The symbol is followed by a number from 1 to 4, this distinguishes the type and origin of each component. Details of the origin of these materials have been reported in reference [1]. Relevant properties are shown in Tables 1, 2 and 3. The particle size distribution of the limestone and fly ash fillers were similar mainly on the silt size range.

There is a marked difference between the two types of filler. Limestone fillers are on average finer than FA fillers and have a higher specific gravity. The shape factor number [2] which is a measure of the sphericity of a particle shows that FA is predominantly spherical in shape while limestone is not. This characteristic of FA allows it to function as a filler in a solid-liquid or solid-plastic composite without unduly increasing the viscosity of the composite.

Table 1 Sand and Aggregate Properties

| Material | Relative Density on Oven dried basis | Relative Density on a saturated and Surface dried basis. | Apparent Relative Density | Water Absorption (% of dry mass) |
|----------|--------------------------------------|--|---------------------------|----------------------------------|
| S1 | 2.489 | 2.494 | 2.502 | 0.210 |
| S2 | 2.383 | 2.402 | 2.430 | 0.808 |
| S3 | 2.534 | 2.547 | 2.568 | 0.512 |
| S4 | 2.579 | 2.595 | 2.621 | 0.611 |
| CA1 | 2.861 | 2.910 | 3.009 | 1.719 |
| CA2 | 2.893 | 2.923 | 2.982 | 1.032 |
| CA3 | 2.728 | 2.756 | 2.807 | 1.030 |
| CA4 | 2.753 | 2.763 | 2.780 | 0.353 |

Table 2 Filler Properties

| Filler | Relative Density | Voids of Dry Compacted filler | Bulk Density in Toluene (g/ml) | % retained on 75 μ m sieve |
|--------------|------------------|-------------------------------|--------------------------------|--------------------------------|
| FA1 | 2.179 | 0.211 | 0.450 | 14.64 |
| FA2 | 2.412 | 0.275 | 0.638 | 12.77 |
| FA3 | 2.249 | 0.281 | 0.344 | 9.16 |
| FA4 | 2.384 | 0.235 | 0.422 | 11.81 |
| L5 | 2.773 | 0.255 | 0.612 | 3.30 |
| L6 | 2.824 | 0.243 | 0.625 | 5.72 |
| L7 | 2.725 | 0.248 | 0.638 | 8.48 |
| Spec. limits | - | - | 0.5 - 0.9 | < 15.00 |

Table 3 Filler Mean Diameters, Specific Gravities and Surface Areas

| Filler Type | Mean Diameter (micron) | Specific Gravity g/cc | Surface Area (m ² /g) | Calculated Surface Area (m ² /g) | Shape Factor |
|--------------------|------------------------|-----------------------|----------------------------------|---|--------------|
| Drax PFA | 14 | 2.179 | 0.196 | 0.215 | 2 |
| Blyth PFA | 10 | 2.412 | 0.248 | 0.213 | 3 |
| Thorpe Marsh PFA | 11 | 2.249 | 0.242 | 0.218 | 3 |
| West Burton PFA | 9 | 2.384 | 0.279 | 0.233 | 3 |
| Ballidon Filler | 7 | 2.773 | 0.309 | 0.217 | 3 |
| Marsden Limestone | 7.4 | 2.824 | 0.287 | 0.171 | 3 |
| Scottish Limestone | 5.4 | 2.725 | 0.407 | 0.180 | 3 |

The bitumen used was a straight run nominal 50 pen grade bitumen. The bitumen properties measured are shown in Table 4.

Table 4 Properties of Bitumen

| | |
|----------------------------|-------|
| Penetration 25 °C (×0.1mm) | 52 |
| Softening Point (R&B) °C | 53 |
| Relative Density | 1.029 |
| Penetration Index | -0.20 |

PREPARATION OF HOT ROLLED ASPHALT MIXES

The proportions of coarse aggregate, sand and filler required to produce size distributions within the specifications given in BS 594: Part 1:1985, were :

Coarse aggregate : Fine Aggregate : Filler
34% : 56% : 10%

The eight aggregate combinations labelled M1 to M8 were used to produce HRA mixes at various mixing and compacting temperatures. An example of the resultant particle size distribution for mix 2 together with BS 594 specification limits are shown in Figure 1.

Specimens were compacted in the laboratory, using the gyratory testing machine (GTM) [3] The main characteristic of the GTM compactor is that it allows the application of an axial static pressure at the same time that the specimen is subjected to a dynamic 'kneeding motion' which resembles the mode of energy applied in the field by construction plant.

For each combination of mixing-compactation temperature, four samples were prepared using the GTM for compaction and measurement of the Workability Index. The compaction conditions in the GTM : Vertical pressure 0.7 MPa, Angle of Gyration 1°, No. of revolutions 30.

These conditions give an energy of compaction of the same order as the energy of compaction applied by 50 blows per side with the Marshall hammer. The mixing and compaction temperatures used in the project are given in Table 5.

Table 5 Mixing and Compaction Temperatures

| Code | Mixing Temp. °C | Compaction Temp. °C | Code | Mixing Temp. °C | Compaction Temp. °C |
|------|-----------------|---------------------|------|-----------------|---------------------|
| T1 | 140 | 125 | T5 | 120 | 105 |
| T2 | 140 | 115 | T6 | 120 | 95 |
| T3 | 130 | 115 | T7 | 110 | 95 |
| T4 | 130 | 105 | T8 | 110 | 85 |

RESULTS FROM THE LABORATORY STUDY

Workability

In this study the method used to assess workability as developed by Cabrera [3, 4], consists of monitoring the specimen height and hence volume reduction during compaction. Knowing the specific gravity of the mix, for any specimen, the porosity can be plotted against the number of compactive revolutions. The experimental line should approximate a linear relation of the form :

$$P_i = A - B \log_{10}(i) \quad \text{A and B are constants.}$$

where A = intercept with the y axis. B = slope of the line. i = number of revolutions.

The Workability expressed by the "Workability Index" (W.I.) is defined as the inverse of the constant A. i.e. the porosity at zero revolutions multiplied by 100.

$$\text{W.I.} = \left(\frac{1}{A} \right) \times 100$$

As expected W.I. values decrease as temperature decreases due to the increase in bitumen viscosity as the softening point is approached. But most importantly, all FA mixes at all mixing and compacting temperatures exhibit higher W.I. values than conventional HRA mixes, an example is shown in Figure 2. This can be attributed to the fact the FA particles have more rounded and less angular texture aiding workability. There is clear evidence that FA mixes will compact better than limestone mixes even at the lowest temperature of compaction used in the laboratory.

Stability and Flow Values

Densities, Marshall Stabilities and Flows were obtained according to BS 598 [5]. In general, Stability values decrease as mixing and compacting temperatures decrease. In all cases, the Stability of the conventional hot rolled asphalt mixes were only slightly higher than their counterpart FA mixes. Nevertheless, the stability of all mixes satisfy the criteria for roads carrying medium traffic (up to 6000 vehicles/lane/day). See Tables 6 and 7 for the stability and flow design parameters.

Table 6 Criteria for the Stability of laboratory designed asphalt.
BS 594 : Part 1 : 1985

| Traffic (commercial vehicles per lane per day) | Marshall Stability of complete mix (kN). |
|--|--|
| Less than 1500 | 2 to 8 |
| 1500 to 6000 | 4 to 8 |
| Over 6000 | 6 to 10 |

Table 7 Asphalt Institute Design Criteria

| | Light Traffic | Medium Traffic | Heavy Traffic |
|----------------|---------------|----------------|---------------|
| Compaction | 2 × 35 | 2 × 50 | 2 × 75 |
| Stability (kN) | 3.33 | 5.33 | 8.00 |
| Flow, (0.25mm) | 8 - 18 | 8 - 16 | 8 - 14 |
| Porosity (%) | 3 - 5 | 3 - 5 | 3 - 5 |

FA mixes exhibit consistently lower flow values than their counterpart conventional mixes at all mixing and compacting temperatures, nonetheless almost all the flow values measured were less than 4 mm.

Porosity and Voids in Mineral Aggregate (VMA)

There is no marked change in VMA values as the temperature of mixing and compaction decreases. Also for each aggregate type, both conventional and FA mixes do not exhibit a great change in VMA values.

Porosity values for all the mixes at all temperatures were below 6%.

Creep Stiffness

The creep test is carried out on duplicate specimens at 40°C. The test lasts two hours, and gives results which allow the characterisation of the mixes in terms of their long term deformation behaviour [6].

Analysis of creep test results carried out on the hot rolled asphalt containing FA filler show the normal variation in stiffness of mix values with respect to stiffness of bitumen. The stiffness of the bitumen was obtained from a Van der Poel nomograph. The nomograph gives values of stiffness as a function of the time of loading, the temperature difference between test conditions, the Softening Point temperature, and the Penetration Index.

From the S_{mix} - S_{bit} experimental values, regression lines were obtained. These regression equations are of the form :

$$\text{Log } S_{mix} = X \text{ Log } S_{bit} + C$$

and were used to obtain the S_{mix} values at one hour loading time. Figure 3 shows an example for mixes 1 and 2.

Determination of the Optimum Bitumen Content (o.b.c.)

The Leeds Design Method [4], recommends that the optimum binder content should be obtained by averaging the binder contents corresponding to the following parameters:

Maximum Stability, Maximum Density, Minimum voids in the mineral aggregate, Maximum compacted aggregate density, Maximum Stiffness.

The optimum value obtained should lie within 3 - 5% porosity and below 4 mm Flow.

The o.b.c.'s for the mixes prepared at different temperatures of mixing and compaction were then averaged and the results used as the o.b.c. for each mix combination independently of the temperature of mixing and compaction. On average the o.b.c.'s of all mixes were very close to 7% for all temperatures [1].

Fatigue Testing Programme

In this part of the programme, an Instron 8033 Servo Hydraulic Dynamic Testing machine was used to produce a sinusoidally shaped loading pulse on the beam specimens. The machine was also equipped with an oscilloscope to aid in monitoring the shape of the applied load and the response pattern. The output data, consisting of the magnitude of the applied load, the approximate piston head position and the number of cycles, were updated and displayed on the visual display unit of the Instron.

To measure the resultant strains on a beam, a PL-60 wire resistance strain gauge having 60 mm length was glued at two locations of one beam side. The central strain gauge was fixed at a location approximately 25 mm above the bottom of the beam. The strains produced by the repeated loading at the center of the beams were amplified by a Differential Strain Amplifier and then transmitted to a data logger which was connected to a computer.

The fatigue test was performed by placing the rectangular beams on a 50 mm thick rubber foundation which had a modulus of elasticity value of 4.3 MPa. The dynamic load was applied to the centre of the beam via a rubber loading block 60 mm wide, see Figure 4. The whole assembly consists of the beam and rubber pad which rests on a very stiff 25 mm thick steel plate which is supported directly on the base of the loading frame.

Method of Analysis

During fatigue testing, sudden failure due to defect propagation in the brittle mode was not detected as the mode of failure in the test configuration, hence brittle fracture and fracture toughness calculations are not applicable. Thermal fatigue or ductile failure where plastic deformation in the region of rupture due to the build up of heat is the more realistic failure mechanism.

By employing a dissipated energy approach the results of different types of dynamic tests, carried out under different sets of conditions and with several types of asphalt mixes, can be described by a single, mix-specific relation : the number of cycles to fatigue is related mainly to the amount of energy dissipated during the test. The occurrence of rest periods, the use of controlled-stress or controlled-strain tests, the effects of frequency and temperature do not significantly influence the dissipated energy relation.

During a controlled strain test the stress amplitude and the phase angle change. This means that for the calculation of the total dissipated energy it is necessary to integrate the functions of stress and phase angle over the number of loading cycles concerned. This integration is approximated by a summation of the energy into fixed intervals of "constant" cycles, i.e. cycles in which it can be assumed that the stress and phase angle in that interval are nearly constant. From the energy relation it follows that at a higher fatigue life of the mix more total energy per unit volume can be dissipated [7].

By using the original strain versus the number of cycles, the cumulative energy dissipated for each beam was calculated up to the point where the test was terminated. Figure 5 shows the relation between the number of cycles to the cumulative dissipated energy value of $60 \times 10^6 \text{ J/m}^3$ for the initial strain at the four main load levels (95 N, 150 N, 260 N and 1400 N). It is clear that FA and ordinary mixes behave in the same manner and there is no distinction between their fatigue properties.

FULL SCALE ROAD TRIAL

Following the successful outcome of the laboratory investigation, a full scale road construction trial to assess the performance of Low Energy Hot Rolled Asphalt (LEHRA) under real intense traffic loading was carried out.

The selection of the mix for the construction of the road trial was indirectly determined by the geographical position in the U.K. of the road selected by Cleveland County Council. The road selected served high traffic volumes which provided realistic conditions for the evaluation of the performance of the LEHRA. It was also a requirement that the road structure should not have reached a service life requiring reconstruction, but one where a strengthening surface layer should be the most acceptable engineering improvement.

A section of the A689, Eastbound slow lane, one mile West of Trunk Road A19, was made available for the construction of the trial section. The most convenient materials were those designated Mix 1 and Mix 2 of the laboratory study.

Materials and Location of the Road Trial

The trial pavement was constructed on April 1991. The plant for the preparation of the bituminous mixes was made available by Tilcon North Ltd., and consisted of a Miller Batch Asphalt Plant of 240 ton/h capacity with delivery of 3 ton mix per batch, located in Blaydon, North Yorkshire.

Two Hot Rolled Asphalt mixes were produced : A control mix containing the conventional limestone filler and an experimental mix containing FA filler designed according to the Leeds Design Method. Both mixes conform to BS594, Part 1: 1985. Designation 30/14.

Analysis of the mix composition produced in the batching plant showed that the mix was identical to the mix designed in the laboratory and described earlier.

Production Sequence

The trial consisted of the production and laying of 70 tonnes of LEHRA and 80 tonnes of conventional HRA in the slow lane, Eastbound carriageway of the A689 Wolviston to Billingham road [8]. The length of the trial road was 320 m and the thickness of the layer was 40mm. The total work for the morning was scheduled to be 150 tonnes.

Evaluation of the production process highlighted the following :

1. The PFA would not flow properly through the silo screw-feed system, flow was maintained by manually rodding the base of the silo. The use of aeration and vibration which is common in the concrete industry will solve this problem.
2. Attempts to match the slow rate of filler feed with an equivalent sand feed rate and the reduction of temperature, caused the drier burner control to become unstable below about 135°C.

The final production temperature of the mixes were as indicated in Table 8.

Table 8 Production Temperatures

| Material | Target Temp. (°C) | Actual Temp. (°C) | Quantity (Tonnes) |
|----------------|-------------------|-------------------|-------------------|
| a) Control HRA | 160 | 140 | 30 |
| b) LEHRA Mix | 130 | 130 | 30 |
| c) LEHRA Mix | 140 | 137.5 | 40 |
| d) Control HRA | 160 | 160 | 50 |

Mix temperatures at the plant were taken using electronic thermocouple type thermometers in accordance with the recommendations set out in BS 598: Part 109: 1990. Because of the long loading time and breezy conditions, there was a drop of around 8°C in the temperature of the material which was first loaded.

A hand held thermal anemometer was used for the measurement of ambient temperature and wind velocity at the site. The results indicated a range of speeds varying between 5 and 7 m/s. Wind gusts of up to 10 m/s were also recorded. The temperature was 20°C ± 1°C.

Energy Use During The Trial

Analysis of gas meter readings on the drum dryer during the plant mixing stage indicated the following :

| | | |
|---------------|--------------------------|---|
| Control Mix - | 257 Therms for 80 Tonnes | - 3.21 Therms / Tonne. (338.6 MJ / Tonne.) |
| LEHRA Mix - | 200 Therms for 70 Tonnes | - 2.86 Therms / Tonne. (301.7 MJ / Tonne.) |

Data for the asphalt mixing plant to December 1990 show an energy cost of production (at a target efficiency of 85%) of £1.01p for asphalts, and 58p for macadams per tonne. Of the 43p difference, 70% is a consequence of the additional moisture content of asphalt sands when compared with crushed rock used in macadams. The other 30% is 'heating' energy; a consequence of the higher mixing temperatures needed for 50 pen. grade bitumens usually used with the asphalts. The substitution of limestone by PFA allowed a reduction in the temperature of the raw materials in the asphalt plant at the heating/mixing stage of production. This reduction in heating energy is equivalent to 30%. Therefore using the difference of heating requirements for HRA and macadams, it can be said that the savings at the heating / mixing stage are 30% of 43 p or 12.9 p / tonne of LEHRA produced.

Table 9 shows the details of the trial road construction, including materials and temperatures of mixing and compaction.

Table 9 Details of the Trial Road Construction.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------------------|-----------------------------|------|------|------|------|------|------|------|------|---------------|------|---------------|------|------|-----------------------------------|------|------|------|------|--------------------|------|------|-----------------------------|------|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Meters from Start | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 81 | 100 | 101 | 120 | 130 | 145 | 146 | 160 | 170 | 180 | 190 | 200 | 201 | 220 | 230 | 240 | 241 | 260 | 270 | 280 | 290 | 300 | 310 | 320 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material (Load No.) | Conventional HRA Design Mix | | | | | | | | | HRA + PFA (1) | | HRA + PFA (2) | | | HRA + PFA (3) | | | | | HRA + PFA (4) | | | Conventional HRA Design Mix | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Temp. at Plant (°C) | | | | | | | | | | 120 | | 130 | | | 140 | | | | | 133 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Temp. Arrive Site (°C) | 157 | | | 153 | | | | | | 116 | | 125 | | | 139 | | | | | 129 | | | 153 | | | 160 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Temp. Hopper (°C) | 155 | | | 152 | | | | | | 111 | | 127 | | | 139 | | | | | 129 | | 129 | | 124 | | 152 | | | 160 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Temp. Screw/Blat (°C) | 145/135 | | | 144 | | | | | | 106 | | 119 | | | 127 | | | | | 124 / 118 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Temp. Roll (°C) | 135 | | | 132 | | | | | | 102 / 94 | | 111 / 114 | | | 88 / 100 88 / 100 110 91 / 92 109 | | | | | 90 90 / 94 109 113 | | | 104 | | 120 / 132 | | 132 | | 132 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| R.O.S. (kg/m ²) | 13 | | | 13 | | | 11.5 | | | 12 | | 15 | | 14 | | 14 | | | 14 | | 13.5 | | 13 | | | 13.5 | | 12.5 | | 14 | | 13.5 | | 14 | | 15 | | 15 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S.M.T.D. (mm) | 0.72 | 0.96 | 1.01 | 1.05 | 0.98 | 0.84 | 0.97 | 0.93 | 1.10 | 0.93 | 0.89 | 0.98 | 0.98 | 0.75 | 1.07 | 1.06 | 0.99 | 0.93 | 0.69 | 0.75 | 0.79 | 0.74 | 0.82 | 1.01 | 1.94 | 0.99 | 1.17 | 1.13 | 1.08 | 0.86 | 1.15 | 0.84 | 1.29 | 0.88 | 0.82 | 1.09 | 1.10 | 0.89 | 1.16 | 1.08 | 0.91 | 0.88 | 1.03 | 0.86 | 0.82 | 0.93 | 0.84 | 0.74 | 0.97 | 1.01 | 0.85 | 0.91 | 0.99 | 1.20 | 1.08 | 0.94 | 7.71 | 0.81 | 0.95 | 0.93 | 1.35 | 1.15 | 0.92 | 0.89 |
| Core No. and Chaining | 1 | | | 3 | | | | | | 4 | | 5 | | 6 | | | 7 | | 8 | | 9 | | 10 | | 11 | | 12 | | 13 | | 14 | | 15 | | 17 | | 208 | | 226 | | 240 | | 254 | | 289 | | | | | | | | | | | | | | | | | | | |

**A 689 Wolviston to Billingham
HRA Trials, laid 11th April 91.**

| | |
|--------------|---------------------------------|
| Distance (m) | Materials |
| 0 - 80 | Control HRA (Limestone Filler). |
| 81 - 100 | HRA with FA Section 1. |
| 101 - 145 | HRA with FA Section 2. |
| 146 - 200 | HRA with FA Section 3. |
| 201 - 240 | HRA with FA Section 4. |
| 240 - 320 | Control HRA (Limestone Filler). |

R.O.S. = Rate of spread of chipping (kg/m²).

S.M.T.D. = Texture depth measurements by Laser Texture Depth Meter (mm).

Note; the two rows of data indicate the near side and off side measurements respectively.

ASSESSMENT OF THE PERFORMANCE OF THE TRIAL PAVEMENT

The following control tests were carried out in the field :

- | | |
|----------------------------------|------------------------------------|
| 1- Traffic Control. | 2- Rut Depth measurements. |
| 3- Surface texture measurements. | 4- Dynamic deflection measurement. |

Cores were obtained from the different sections of the pavement and laboratory measurements of porosity, density and stability were carried out.

Traffic Count for A689 Eastbound

Cleveland County Council and Leeds University carried out measurements of vehicle flows, these were :

| | |
|--|---------------------|
| Total number of Vehicles in both directions = 8877 | |
| Total HGV's in both directions = 2832 | % of HGV's = 31.9 % |
| Total number of Vehicles Eastbound = 4371 | % of HGV's = 32 % |
| Total number of Vehicles Westbound = 4506 | % of HGV's = 31.7 % |

Rut Depth Measurements

Initially rut depth measurements for the entire trial length were taken on 5 dates initially using a Straight Edge (3 m in length). The average rut depth values showed that, it was not possible to draw any trends, since there is no evidence of road deterioration.

Realizing the need for a more accurate means of monitoring rut depth profiles, which does not entail a worker having to lie on a wet road surface on a cold day taking readings using a small meter rule to an unrealistic accuracy of 1 mm, a rut depth measuring beam was developed at the laboratories of CEMU, University of Leeds.

The Leeds Rut Depth Measuring Beam (LRDMB) automates the process of rut depth measurement. A measuring arm, follows the pavement rut depth profile, this is connected to a carriage that runs along the beam length. A hand held microcomputer then digitizes and stores the electrical signals sent off from the measuring arm at every 100 mm traveling distance along the beam. The signals are generated via an angular variable differential transformer that measures the change in angle that the arm makes as it follows the irregularities of the pavement surface. The digital values are then transferred to a template on a spreadsheet and this converts the readings to actual deflections in mm and plots the resulting profile.

A longitudinal-section of the beam constructed is shown schematically in Figure 6. Figure 7 shows the longitudinal rut depth profiles along the entire trial obtained using the LRDMB. The experiment confirmed that the road sections made with LEHRA showed rut depth values which were comparable with those of sections containing the conventional HRA.

Surface Texture Measurements

Texture depth measurements by Laser Texture depth meter, measured in accordance with the specifications for Roads and Bridges clause 929 [9], were also taken. An example of the results is shown in Table 9, and the second, a more recent set is presented in Table 10.

Dynamic Deflection Measurements

Deflection measurements taken on the trial road using a Deflectograph [10,11,12] are shown in Figure 8. The trends shown in this Figure lead to the clear conclusion tht LEHRA and HRA deflect to the same extent confirming the LEHRA is as good a material as the conventional HRA.

Table 10 Texture Depth Measurements

| Distance (m) | Near Side Wheel Track | Off Side Wheel Track | Distance (m) | Near Side Wheel Track | Off Side Wheel Track |
|--------------|-----------------------|----------------------|--------------|-----------------------|----------------------|
| 0 - 10 | 0.87 | 0.94 | 170 - 180 | 1.15 | 1.19 |
| 10 - 20 | 1.15 | 0.96 | 180 - 190 | 1.31 | 1.04 |
| 20 - 30 | 1.14 | 0.75 | 190 - 200 | 1.22 | 1.15 |
| 30 - 40 | 1.12 | 0.83 | 200 - 210 | 1.18 | 1.02 |
| 40 - 50 | 1.25 | 1.11 | 210 - 220 | 1.33 | 1.02 |
| 50 - 60 | 1.27 | 1.2 | 220 - 230 | 1.25 | 1.07 |
| 70 - 80 | 1.17 | 1.08 | 230 - 240 | 1.16 | 1.07 |
| 80 - 90 | 1.27 | 1.24 | 240 - 250 | 1.07 | 1.15 |
| 90 - 100 | 1.26 | 1.15 | 250 - 260 | 1.08 | 1.12 |
| 100 - 110 | 1.23 | 1.13 | 260 - 270 | 1.22 | 1.02 |
| 110 - 120 | 1.28 | 0.95 | 270 - 280 | 1.06 | 0.87 |
| 120 - 130 | 1.23 | 1.07 | 280 - 290 | 1.11 | 0.82 |
| 130 - 140 | 1.27 | 0.96 | 290 - 300 | 1.22 | 0.9 |
| 140 - 150 | 1.09 | 0.93 | 300 - 310 | 1.21 | 1.01 |
| 150 - 160 | 0.98 | 1.11 | 310 - 320 | 1.11 | 1.2 |
| 160 - 170 | 1.16 | 1.06 | 320 - 330 | 1.0 | 1.02 |
| | | | 330 - 340 | 0.84 | 0.95 |

Laboratory Tests

Cores taken at various times during the monitoring period of 4 years showed that the FA and conventional HRA performed satisfactorily. The details of measurements carried out on these cores have been reported in references [8 and 13].

CONCLUSIONS

From the results obtained in the Laboratory the following conclusions are offered :

- Fly ash is known to possess predominantly spherical particles when observed under an electron microscope, this enables them to improve the packing properties of HRA. FA particles tend to occupy more bulk volume per unit weight as compared with the more familiar irregular surfaced limestone powder particles. This can be observed from the lower bulk density in the Toluene test.
- FA filler hot rolled asphalt has far higher workability index than conventional hot rolled asphalt for any of the aggregate combinations used. This finding implies that hot rolled asphalt containing FA can be mixed and compacted at temperatures as low as 110 °C - 85 °C respectively without impairing its engineering and performance properties.
- The savings in energy input are considerable and thus FA-HRA can be classed as a low energy material.
- Replacement of limestone filler with FA does not affect the optimum bitumen content of hot rolled asphalt.
- The Stability and Flow of the FA mixes satisfy the criteria for medium traffic (up to 6000 CVd), laid down by the Ministry of Transport and the Asphalt Institute of U.S.A. for the range of temperatures tested.
- Using the Energy approach to eliminate the effect of temperature, it is shown conclusively that mixes containing FA replacement behaved in a similar manner to conventional HRA mixes under repetitive flexural loads. Under a particular stress level, both types of mixes needed the same number of cycles to dissipate a chosen quantity of energy.

From the results of full scale trials, the following conclusions are offered

Laying Operations

It was clear that using FA as a filler has allowed the temperature of mixing and compaction to be lowered without affecting the optimum binder content. This not only has a significant benefit in terms of heating energy, but also encourages laying under adverse winter conditions. The net energy saving amounts to 12.9 p / tonne of the total energy expenditure in the preparation of the mix. Other savings regarding laying at low temperature and avoidance of waste due to cooling have not been quantified.

Laboratory Results

Hot Rolled Asphalt with pfa fillers conformed to BS 594: 1985 specifications and were able to perform as well as the materials containing the conventional Limestone fillers. Results from cores tested in the Laboratory were within the specifications for roads carrying up to 6000 CV's per day.

Road Monitoring

Monitoring of the road has been continuously carried out : rut depths, surface texture and deflectograph measurements have been analysed. There was no sign of any form of distress, and the trial sections have shown excellent performance.

Hot Rolled Asphalt with PFA as a filler has performed as well as the conventional HRA containing Limestone filler. Cleveland County Council will continue to monitor the performance of the trial section so that information regarding its long term performance can be confirmed.

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Figure 1 Particle Size Distribution for Mix 2.
Coarse & Fine aggregates = Birtley, Filler = Birtley Limestone.

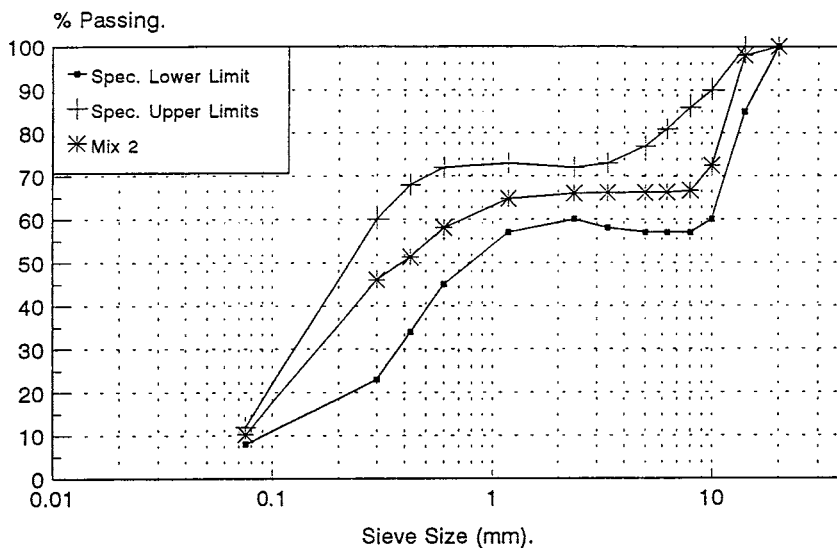


Figure 2 Workability Index values v.s. bitumen content for mixes M1 and M2 at Temperatures T3 and T7

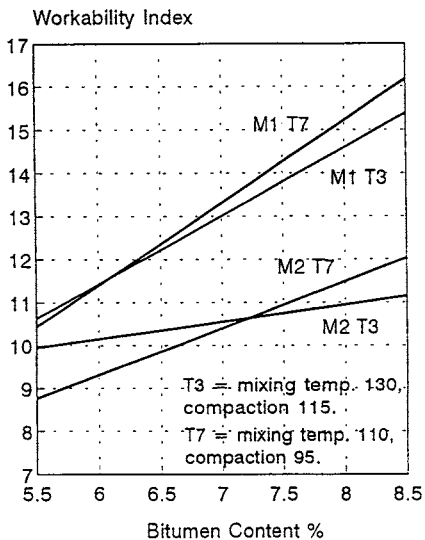


Figure 3 Stiffness of mix (MPa) v.s. bitumen content

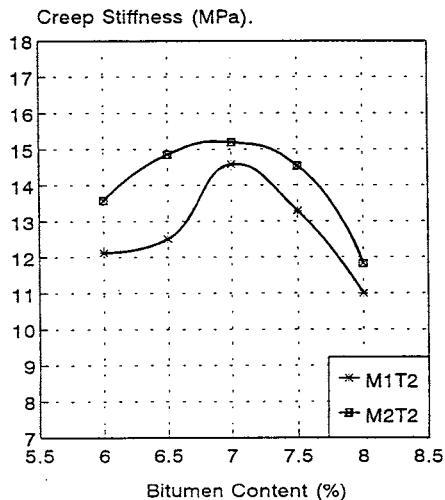


Figure 4 Fatigue Loading Configuration
Insulated Wooden Chamber



Figure 5 Number of cycles to dissipate 60 million J/m³ per unit volume v.s. initial strain for all beams

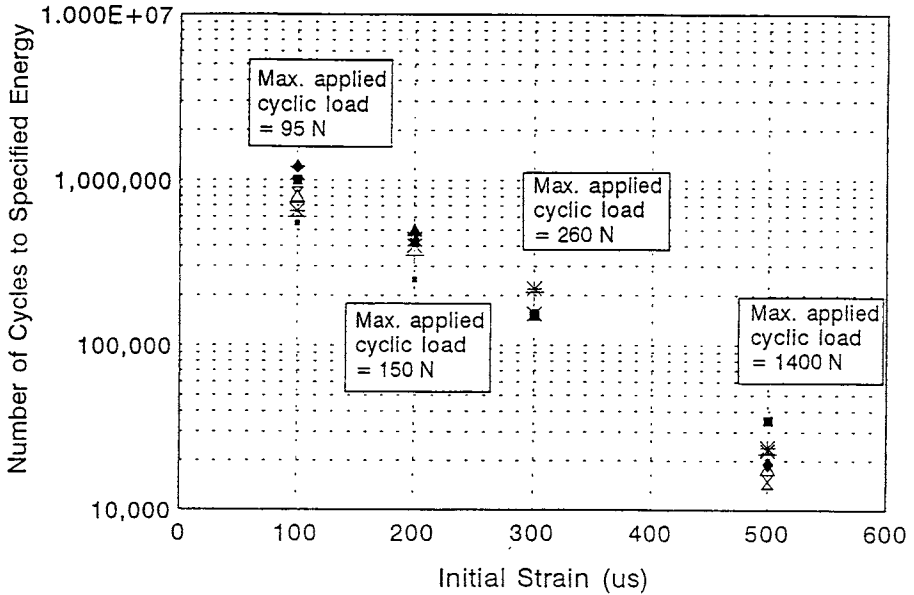


Figure 6 Schematic Diagramme of the Leeds University Rut Measuring Device.

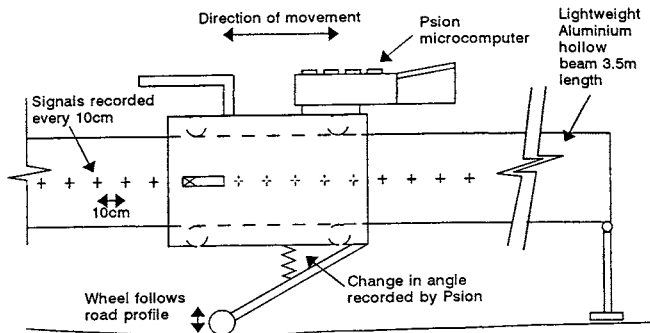


Figure 7 Longitudinal Rut Depth Profiles

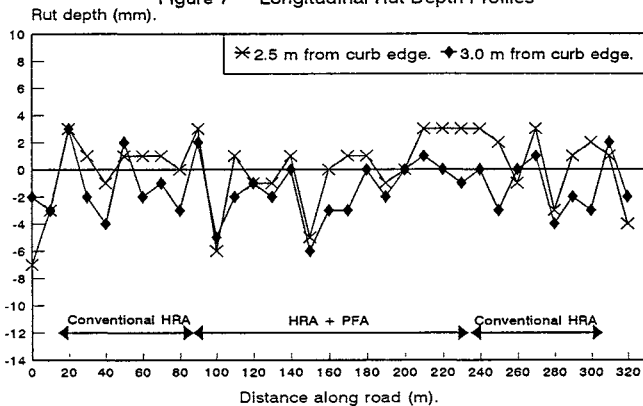


Figure 8 Offside Wheel Path Deflections
A689, Eastbound Trial Area.
Output from Deflec3 Programme at 24/05/91.

