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Assessment of the performance of off-site recycled bituminous material

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ASSESSMENT OF THE PERFORMANCE OF OFF-SITE RECYCLED BITUMINOUS MATERIAL

ABSTRACT

The recycling of bituminous basecourses and roadbases has the potential to save energy and natural resources and to reduce the cost of major maintenance. These savings can only be realised if a pavement containing recycled material performs as well as one produced conventionally. In this report two trials are described; the first is a pilot-scale trial and the second is a full-scale trial on a trunk road. The recycled materials were compared to virgin materials in performance-related laboratory tests and the in-service performance was assessed in the full-scale trial. The cost of production and energy usage during construction were determined. The trials demonstrated that recycled material can comply with the relevant specifications when it is produced using modified drum-mixers and laid using conventional plant. The in-service performance of a pavement containing up to 60 per cent recycled material was as good as one constructed with conventional material. Cost savings of up to 30 per cent can be made when recycling at 60 per cent. Energy savings are worthwhile but contribute only a small part to the cost savings.

1. INTRODUCTION

The potential for cost effective recycling of bituminous road-making material has long been recognised. This process is used in many countries and in some it is adopted as a standard alternative for both construction and maintenance (18th World Road Congress, 1987). In the UK, a plentiful supply of good quality aggregate and relatively short distances between production plant and site has reduced the need to apply this technology. However it does have the potential not only to reduce costs but to save energy and other finite natural resources.

Research reported by Edwards and Mayhew (1989) has shown that in-situ recycling of wearing courses by the Remix and Repave processes can be cost effective, with the primary savings being in material costs. There should be a greater potential for reducing material costs by recycling roadbase and basecourse materials because these layers form the greater part of a bituminous pavement structure. However this potential can only be realised if the recycled material can be produced to yield a pavement with a performance similar to one constructed with conventional material.

To assess the in-service performance and mechanical properties of recycled roadbase and basecourse materials two trials were constructed. The first was a pilot-scale trial in which recycled dense bitumen macadam (DBM) roadbase and basecourse, produced to comply with British Standard BS 4987 (British Standards Institution, 1973), were compared with conventional materials. This trial proved successful so it was decided to construct a full-scale road trial.

The full-scale trial was part of major reconstruction works on the A20 trunk road near Ashford. The objectives of this trial were to evaluate the properties of recycled hot-rolled asphalt (HRA) roadbase and basecourse material from performance related tests and to assess the in-service performance of the test sections. In addition the Department of Energy compared the energy required to produce recycled materials with that required to produce conventional materials (Hubert, 1987). In this Report the principles of producing recycled material at a central plant are briefly outlined and an assessment made of the performance of recycled macadam and rolled asphalt roadbase and basecourse. Finally, the energy and cost savings that may be made using the recycling process are summarised.

2. CENTRAL PLANT RECYCLING OF BITUMINOUS MATERIAL

When mixing reclaimed bituminous material in conventional plants it is essential to prevent overheating of the bitumen coating on the reclaimed material. This is achieved in many modern drum-mixers by feeding the reclaimed material through a collar fitted to the drum which is positioned a sufficient distance away from the burner. The production process using a typical drum-mixer with recycling collar is shown in Figure 1.

The essential requirements for recycled material are that it must have a performance similar to that of new material and be as cost effective. One way of judging its fitness for purpose is for the recycled material to comply with the relevant British Standard specification. To achieve this objective the reclaimed material should have been mixed originally to comply with a specification similar to that specified for the works. A sufficient quantity of reclaimed material must be available for all the construction requirements. The choice of specification will be influenced by the type of material needed to meet pavement design requirements and the composition of the reclaimed material.

In the production of recycled materials virgin aggregates are blended with the reclaimed material to bring the resultant mix composition within the specification. This, together with heating and emission constraints during mixing, usually limits the amount of reclaimed material that can be incorporated in the recycled material. The bitumen in the reclaimed material will have hardened during the original mixing and subsequently in the road,

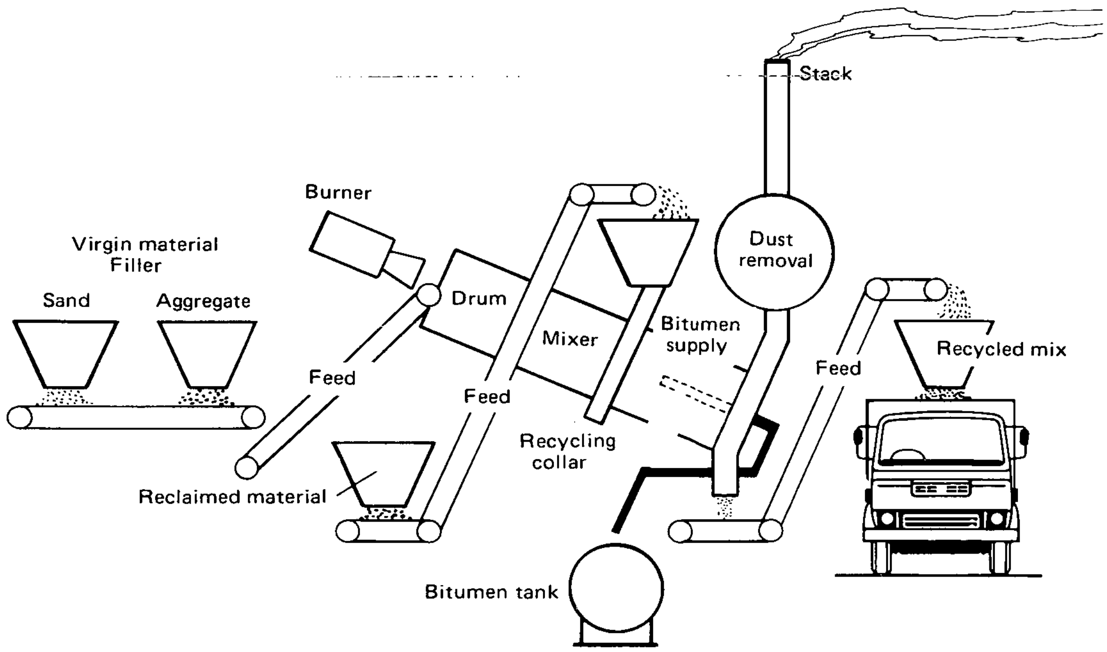

Fig. 1 Off-site recycling by modified drum-mixer

therefore a softer binder has to be added to the reclaimed material during recycling to restore the properties of the bitumen specified in BS 3690 (British Standards Institution, 1982). A flow chart illustrating the procedure for producing recycled material and the method of calculating the amount and grading of aggregate and the penetration of new bitumen required to produce a recycled mix that complies with the relevant specification for roadbase or basecourse is given in Appendix A.

Sources of suitable reclaimed material for specific projects need to be identified either in existing pavements or in stockpiled planings. The reclaimed material must be consistent, as variations will be reflected in the composition of the recycled material. Material that was produced originally to comply with a British Standard Specification and has been reclaimed from trunk roads and motorways that have performed satisfactorily should provide good feedstock. The composition and variability of potential reclaimed material that is still in the road should be assessed from cores with the final design of the recycled mix being based on the actual grading of reclaimed material to take account of aggregate degradation resulting from the reclamation process.

3. DESCRIPTION OF TRIALS

3.1 THE PILOT-SCALE TRIAL

Trial materials with different percentages of reclaim were designed to conform to BS 4987: 1973 as shown in Table 1.

The recycled material containing 30 per cent reclaim complied with the specification with little difficulty. The higher percentages (38 per cent for roadbase and 50 per cent for basecourse) of reclaim were the most that could be incorporated into the recycled mixes using the available feedstock and still comply with the specification. The reclaimed material for the trial was obtained from a stockpile of asphalt planings removed from the M4 Motorway. Control materials were produced conventionally to provide a reference for performance measurements.

The trial was conducted, under cover, on the concrete floor of a large hangar. Three test sections, constructed in timber bays, consisted of a control (virgin material) and two sections of recycled material containing the different quantities of reclaimed material. The trial was conducted in two parts; firstly the sections were constructed with a 100mm thick DBM roadbase and secondly with a 60mm thick DBM basecourse as shown in Table 1.

TABLE 1

Recycled materials in pilot-scale trial

Material Specification	*Reclaimed material (%)*		
28mm DBM roadbase	0 (control)	30	38
28mm DBM basecourse	0 (control)	30	50

A Bomag AR-6 mobile mixer was used to produce the materials.This mixer was designed principally for re-heating and remixing material for road patching. It consisted of a powered mixing drum heated by a propane burner. All the mix components were fed into the drum from a large capacity hopper mounted at the front of the machine and the mixed material was discharged at the rear. It was then spread by hand and compacted with an 8 tonne deadweight roller.

Samples of freshly mixed material were taken for compositional analysis and cores and slabs were cut from the laid materials to provide specimens for performance-related laboratory tests.

3.2 THE FULL-SCALE ROAD TRIAL

The road trial was carried out in the slow lane of the westbound carriageway of the A20 trunk road, near Ashford. Nine test sections were constructed as shown in Figure 2. The total thickness of the bituminous layers was 280mm to provide a design life of 9 million standard axles (msa).

The virgin and recycled asphalt roadbase and basecourse were produced to BS 594:Part 1:(1985). Both basecourse and roadbase were produced with three levels of reclaimed material, 0, 40 and 60 per cent. The reclaimed material came from the upper 80mm of existing surfacing and basecourse material.

The asphalt planings were transported from the site to a mixing plant approximately 90km away. All the trial materials, except for the roadbase of Section 4, were mixed in an Ermont TSM 21 drum-mixer; the roadbase material for Section 4 was mixed at another location in a Parker batch-mixer. The mixed material was laid using a conventional Blaw Knox asphalt paver and compaction was achieved with an 8 tonne vibrating roller.

4. LABORATORY MEASUREMENTS

4.1 MATERIAL COMPOSITION

Compositional analysis and bitumen recovery were carried out in accordance with BS 598:1974 on samples of fresh material. The mean analysis results for the DBM roadbase and basecourse from the pilot-scale trial are given in Table 2.

The analysis results of the fresh material showed good compliance with BS 4987:1973. The low penetration of the bitumen recovered from the mix containing 38 per cent reclaimed material was caused by this material having to be reheated and remixed.

The mean compositional analysis of material from the full-scale road trial is given in Table 3. Analysis of samples showed that 70 per cent of roadbase and 83 per cent of basecourse complied with BS 594 (Part 1):1985. The compositions of the recycled and virgin materials were very similar and complied equally well with the Standard. The principal difference was that the recycled material contained 3 to 5 per cent more filler (material passing the 0.075 mm sieve) than the virgin material, a consequence of the reclaiming process.

When recycling a large proportion of the mix, it is vital that reclaimed materials are consistent and that they are thoroughly tested. In this carefully controlled trial a high degree of compliance of the recycled materials was achieved. However it would be desirable initially to monitor performance related material tests as well as compliance on the early application of central plant recycling carried out under normal contractual conditions.

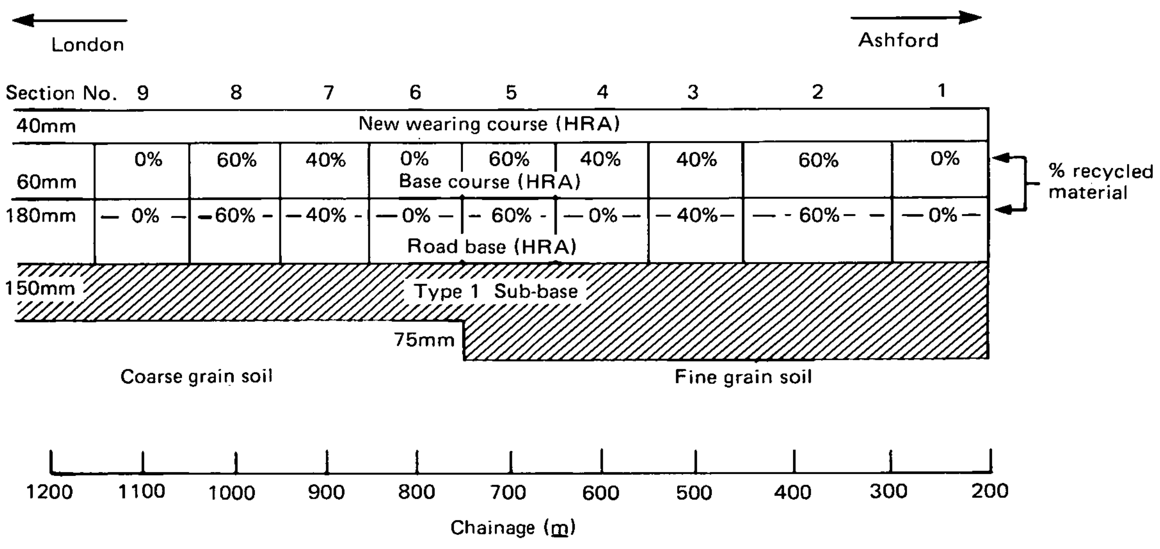

Fig. 2 Cross-section of A20 trial Ashford

TABLE 2

Mean compositional analysis of pilot-scale trial material

BS sieve size (mm)	% Recycled Specified	DBM Roadbase 0	DBM Roadbase 30	DBM Roadbase 38	Specified	DBM Basecourse 0	DBM Basecourse 30	DBM Basecourse 50
				Mean aggregate grading (% passing)				
37.5	95 - 100	100	100	100	-	100	100	100
28	70 - 94	93	93	96	90 - 100	99	95	97
20	-	63	71	65	71 - 95	82	83	79
14	56 - 76	60	64	58	58 - 82	64	70	68
10	-	55	57	52	-	46	56	57
6.3	44 - 60	51	50	45	44 - 60	35	42	47
3.35	32 - 46	41	38	33	32 - 46	29	34	37
1.18	-	34	29	27	-	26	29	30
0.3	7- 21	18	17	18	7 - 21	16	18	18
0.075	2 - 8	7	6	7	2 - 8	8	7	7
Binder (% by mass)	2.9 - 4.1	3.6	3.3	3.5	4.1-5.3	4.9	4.6	4.6
Recovered binder Pen (25°C)		85	70	40		81	54	67

TABLE 3

Mean compositional analysis of material from A20

BS sieve size (mm)	% Recycled Specified	HRA Roadbase 0	HRA Roadbase 40	HRA Roadbase 60	Specified	HRA Basecourse 0	HRA Basecourse 40	HRA Basecourse 60
				Mean aggregate grading (% passing)				
37.5	90 - 100	99	99	99	-	-	-	-
28	70 - 100	82	84	88	100	100	100	100
20	45 - 75	63	67	72	90 - 100	93	96	97
14	30 - 65	52	58	62	30 - 65	42	53	61
10	-	42	51	52	-	37	44	52
6.3	-	39	44	43	-	36	39	44
2.36	30 - 44	37	38	37	30 - 44	35	36	39
0.6	10 - 44	35	36	34	10 - 44	34	34	37
0.212	3 - 25	17	20	21	3 - 25	18	20	22
0.075	2 - 8	2.7	6.1	7.1	2 - 8	3.3	5.9	7.3
Binder(% by mass)	5.1 - 6.3	5.1	5.6	5.2	5.1 - 6.3	5.2	5.4	5.5
Recovered binder Pen (25°C)		37	39	38		32	33	35
Softening Point of recovered binder (°C)		55.4	54.0	56.3		58.4	57.1	56.7

4.2 DEGREE OF COMPACTION

Cores were cut from the compacted pilot-scale trial material and their densities were measured using a γ-ray core scanner which assessed the uniformity of compaction with depth. The overall level of compaction was then assessed in the percentage refusal density (PRD) test as described in the Specification for Highway Works (Department of Transport, 1986). The density and PRD results obtained from the cores are given in Table 4. The average PRD for both recycled and control materials easily exceeded the minimum value of 93 per cent required by the Specification for Highway Works (1986).

TABLE 4

Density of compacted material from pilot-scale trial

Material	*Mean Density*	*PRD* (Mg/m^3)
DBM roadbase		
0% recycled	2.32	95.1
30%	2.33	95.1
38%	2.26	94.5
DBM basecourse		
0% recycled	2.42	98.7
30%	2.43	98.8
50%	2.37	97.7

The densities of the HRA materials in the full-scale trial were measured 24 hours after laying in situ using a nuclear density meter. The values given in Table 5 show that the densities of the recycled and control materials were similar.

4.3 ELASTIC MODULUS

Elastic modulus provides a measure of the load spreading properties of bituminous roadbase and basecourse. The elastic modulus was measured on specimens cut from cores taken from the trial pavements. Roadbase specimens, 300mm long by 100mm square section, and basecourse specimens consisting of composites of samples bound by a thin layer of plaster, were loaded uniaxially in sinusoidal tension and compression over a frequency range from 0.2 to 30Hz and at temperatures between -10°C and 30°C. The values of elastic modulus of each material are compared in Table 6 at a temperature of 20°C and a frequency of 5 Hz, the reference values recommended by Powell, Potter, Mayhew and Nunn (1984).

The coefficient of variation for individual materials was typically 10 per cent and differences in elastic modulus between the recycled and virgin material were not significant at the 5 per cent level. The values in Table 6 are within a range of values measured on other materials meeting current specifications.

However when the load was applied at low frequency and high temperature, potentially the most damaging conditions, the elastic modulus of the virgin HRA roadbase material was consistently greater than the recycled material. On the other hand the elastic modulus of the recycled DBM roadbase samples was consistently greater than the virgin material. For the basecourse, there was no difference between the recycled and virgin material.

4.4 FATIGUE RESISTANCE

It is important that bituminous roadbase material should not be unduly susceptible to fatigue under repeated traffic loading. Although they underestimate in-service performance, laboratory tests provide an indication of the relative fatigue resistance of different mixes. Specimens, similar to those used in the elastic modulus tests, were loaded uniaxially in sinusoidal tension and compression under conditions of controlled constant dynamic stress. The applied stresses, in the range of 0.05 to 0.5 MPa, were applied at a frequency of 25 Hz and temperature of 25°C to produce strains similar to those generated near the bottom of the roadbase by a heavy moving wheel load.

TABLE 5

Density of compacted material from A20 full-scale trial

Material	Mean density (Mg/m^3)	Standard deviation	Percentage of theoretical density (%)	Standard deviation (%)
HRA roadbase				
0% recycled	2.376	0.028	96.7	1.16
40%	2.348	0.028	94.8	1.12
60%	2.384	0.047	96.3	1.92
HRA basecourse				
0% recycled	2.466	0.024	96.9	0.95
40%	2.483	0.029	97.9	1.16
60%	2.466	0.061	97.7	2.40

TABLE 6

Elastic modulus of recycled and virgin materials at 20°C and 5 Hz.

DBM (pilot-scale trial) Percentage recycled	Elastic modulus (GPa) Roadbase	Elastic modulus (GPa) Basecourse	*HRA (A20 full-scale trial)* Percentage recycled	Elastic modulus (GPa) Roadbase	Elastic modulus (GPa) Basecourse
0	2.8	2.8	0	4.4	3.0
30	2.8	2.7	40	3.8	3.4
50	-	2.3	60	3.8	2.6

The initial tensile strain and the number of cycles to failure were measured for each specimen and used to produce the fatigue life relationships shown in Figure 3. The value for the initial tensile strain to achieve a life of 10^4 cycles is given for different materials in Table 7. The results indicate that recycling bituminous roadbase does not adversely affect the fatigue life.

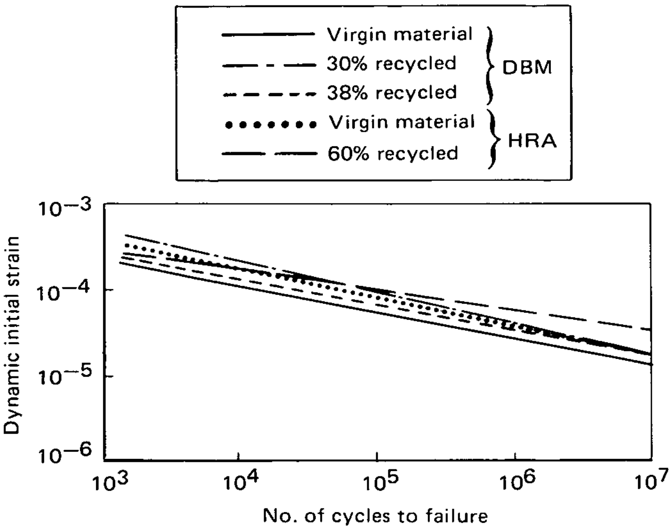

Fig. 3 Fatigue relationships for recycled and virgin roadbases (25Hz 25°C)

TABLE 7

Fatigue test results at 25°C and 25Hz

Material	Initial tensile strain to achieve a life of 10^4 cycles (Strain x 10^{-6})		
% recycled	0%	30%	38%
Pilot-scale trial DBM roadbase	112	224	133
% recycled	0%	40%	60%
A20 Full-scale trial HRA roadbase	170	-	170

4.5 RESISTANCE TO PERMANENT DEFORMATION

Permanent deformation of bituminous roadbases and basecourses can occur particularly in heavily trafficked situations and contribute significantly to wheeltrack rutting especially in thick bituminous pavements. The resistance to permanent deformation of the trial materials was measured using the uniaxial creep test. Specimens were cut from the trial pavements and their deformation resistance was expressed in terms of creep stiffness, defined as the ratio of axial stress to strain after 10^4 seconds at a constant temperature of 30°C. The test method employed was that given in the British Standard Draft for Development DD 185 (British Standards Institution, 1990). Table 8 gives the mean and standard deviation (SD) of creep stiffness for each material.
The recycled macadams showed a greater resistance to permanent deformation than the virgin macadam. For the recycled asphalt roadbase, the creep stiffness value of 4.6 MPa, although low, is within the range of values common to both hot-rolled asphalt and dense bitumen macadam, and to asphaltic concretes, as reported by Claessan, Edwards, Sommer and Uge (1977) and also

TABLE 8

Deformation resistance of virgin and recycled materials measured in a uniaxial creep test at 30°C

Material	Creep Stiffness after 10^4 sec MPa *Roadbase* Mean	*Roadbase* SD	*Basecourse* Mean	*Basecourse* SD
Pilot-scale trial DBM				
0%	9.2	2.5	5.5	1.5
30%	14.4	5.2	10.9	3.0
38%	12.0	3.7	-	-
50%	-	-	10.7	1.4
Full-scale trial HRA				
0%	11.9	3.3	10.6	5.0
0%(Section 4)	4.1	0.8	-	-
40%	4.6	1.6	8.9	2.8
60%	4.6	1.3	5.0	0.6

by Hills, Brien and Van der Loo (1974). The virgin roadbase in Section 4 of the full-scale trial, which was mixed in the batch-mixer, performed differently from the other materials; this result is given separately and was not used to calculate the mean stiffness of the virgin material in order that the comparison of mixes is confined to those for one plant only.

Creep stiffness is greatly influenced by the stiffness of the binder and a detailed investigation (reported in Appendix B) confirmed that the recycled and virgin DBM had similar resistances to deformation. It also showed that the recycled HRA mixes, although less resistant to deformation than the virgin HRA at the same bitumen stiffness, were stable at low bitumen stiffnesses. In the road they would be expected to perform in a similar manner to virgin material, even at high temperatures and long times of loading. The virgin HRA roadbase mixed in the batch-mixer however was less stable when the bitumen stiffness was low and therefore it might be less resistant to rutting at high temperatures or at low traffic speeds.

5. IN-SERVICE PERFORMANCE OF A20 TRIAL

5.1 DEFLECTOGRAPH SURVEYS

A deflectograph survey was carried out one month after opening in and then annually to determine the relative performance of the virgin and recycled sections. Deflection surveys are generally not carried out on new construction until the road has been open to traffic for about a year because further compaction may occur under traffic and the stiffness of the subgrade might change as the moisture content attains an equilibrium condition after the disturbance caused by the construction process.

The lives of the various test sections were predicted on the basis of the 85 percentile deflection using the method described by Kennedy and Lister (1978). Table 9 gives the residual lives of all the test sections for each set of deflection measurements. It shows that the residual life of the test sections containing recycled materials are at least as long as those with conventional materials. The residual life of one of the conventional sections (Section 6) can be seen to be substantially shorter than that of the other sections. This may be due to a weakness in the underlying foundation, but this could only be proved by a structural survey to identify the reason for the high deflections. In 1988 the deflections were measured when the temperature of the road surface was rising very quickly and for normal maintenance purposes these measurements would be disregarded. They are therefore excluded from Table 9.

5.2 RUT MEASUREMENTS

Rut-depths in the nearside wheelpath were measured using a straight edge at 20m intervals along the road at the same time as the deflectograph surveys. The mean rut-depths and standard deviations (SD) for each treatment are given in Table 10 together with an estimate of the cumulative traffic loading when the measurements were made.

After four years of service it can be seen that development of wheel track rutting is not influenced by the presence of recycled roadbase and basecourse layers. Measurements on individual sections however tended to vary along their lengths as indicated by the values of standard deviation. The sections of conventional material had the greatest range of rut depth. The severest rutting was observed in Section 4, with the virgin roadbase made in the batch-mixer; this result was anticipated from the laboratory creep test measurements.

6. STRUCTURAL DESIGN IMPLICATIONS

The trials have shown that recycled DBM and HRA roadbase and basecourse can be mixed, laid and compacted to comply with British Standard Specifications. The recycled materials are structurally equivalent to virgin materials in laboratory tests and after four years in

TABLE 9

Predicted life of test sections

Section	Percent reclaim	*Residual life (msa)* 1986	1987	1989	1990
1	0	10.4	12.2	7.4	8.3
2	60	24.3	12.3	14.5	14.9
3	40	25.7	17.1	18.1	19.6
4	40/0	14.7	8.4	8.3	11.3
5	60	16.1	10.8	11.3	12.1
6	0	12.3	4.5	3.1	4.1
7	40	21.8	7.5	6.8	10.9
8	60	27.2	7.6	7.0	10.1
9	0	27.2	9.5	6.1	9.4

TABLE 10

Development of rutting

Treatment Basecourse/Roadbase	*Year* msa	*1986* 0	*1987* 0.7	*1988* 1.4	*1989* 2.2	*1990* 3.0
				Rut depth (mm)		
0% / 0%	mean	0	1.3	2.3	4.4	5.6
	(SD)	(0)	(0.5)	(1.3)	(2.6)	(2.9)
40% / 0%	mean	0	3.7	5.3	7.0	9.3
	(SD)	(0)	(0.9)	(1.4)	(1.3)	(1.3)
40% / 40%	mean	0	1.7	2.3	4.9	5.9
	(SD)	(0)	(0.1)	(0.7)	(1.7)	(2.2)
60% / 60%	mean	0	1.9	2.6	4.5	6.0
	(SD)	(0)	(0.5)	(0.8)	(1.4)	(1.6)

service the recycled HRA appears to be performing as well as virgin materials. In the pilot-scale trial the DBM was mixed in a small mixer and laid by hand, but it could no doubt be mixed, transported and laid using construction plant similar to that used on the full-scale trial.

The specifications with which new materials have to comply is a major factor in determining the suitability of a particular reclaimed material for production of the mix. Generally the most appropriate reclaimed material is one that was mixed originally to the same specification as that covering the recycled material.

Heavy-duty macadam (HDM), which has superior structural properties compared with conventional macadam, is a material that should be well suited for production by recycling. It differs from conventional DBM in that it contains up to 11 percent filler and 50 pen binder. Bituminous materials reclaimed by cold planing are generally rich in filler and contain hardened bitumen of low penetration. Consequently they should be suitable for the production of HDM. Recycling bituminous materials to comply with the HDM specification should therefore make best use of the reclaimed material by being cost effective and producing a material of greater structural strength.

7. COST AND ENERGY SAVINGS

7.1 COST SAVINGS

Costs of the A20 trial and those from other sites were used to calculate general cost savings from off-site recycling of basecourse and roadbase. The results are summarised in Table 11. All comparisons relate to the total cost of virgin asphalt produced at a quarry 87 km from the road site.

The major savings from off-site recycling were due to the use of less bitumen, sand, stone and filler. The largest additional cost was transport of planings. However, some of this expenditure might have been saved if the planings had been transported to the mixer in the lorries used to deliver the asphalt. It is estimated that even greater savings might be possible if the mixing plant is located at the construction site.

TABLE 11

Component costs of producing HRA roadbase (percentage of total)

Percentage Recycled	0	40	60
Transport costs :-			
Delivery of planings	0	9	13
Delivery of asphalt	29	29	29
Raw material costs:-			
Stone	19	14	11
Sand	7	3	1
Filler	3	0	0
Bitumen	39	24	14
Mixing plant fuel	3	3	3
Total	100	82	71

7.2 ENERGY USED IN PRODUCTION

The amount of energy consumed in the production, delivery and construction of basecourse and roadbase material was determined in an energy audit made for the Department of Energy at the A20 Ashford trial by Hubert. (1987). Energy savings of 8 and 14 per cent were achieved by recycling at 40 and 60 per cent respectively. Almost all the savings were due to the smaller quantity of new material being required and hence less energy being used for extraction and transportation. Slightly less energy was required in the mixing because the reclaimed material had a lower moisture content than the new aggregate.

It was estimated that for 40 and 60 per cent recycling energy savings would have improved to nearly 30 and 40 per cent respectively if the mixer had been located on-site at Ashford. These additional savings would have been due to the greater reduction in energy for transporting the mixed asphalt in comparison to the increase in energy required for transporting the raw materials. These increases in energy savings do not take account of the energy required to dismantle, transport and reassemble the mixing plant on site. In practice it would appear that mixing plants are rarely moved to the road site, partly because of difficulties of acquiring land and getting planning permissions for storing and handling materials.

8. CONCLUSIONS

A full-scale trial has been carried out which demonstrated that bituminous roadbase and basecourse material containing up to 60 per cent reclaimed material can be produced to comply with British Standard specifications in modified off-site mixers. It can be transported, laid and compacted using conventional plant. A 30 per cent saving in cost and some saving in energy can be achieved using this process.

In laboratory tests to measure elastic modulus, fatigue resistance and resistance to deformation, recycled dense bitumen macadam performed similarly to virgin material. Recycled hot rolled asphalt performed similarly to virgin material except that its initial resistance to deformation was slightly lower.

After four years in service, test sections of recycled hot rolled asphalt roadbase and basecourse containing up to 60 per cent reclaimed material have performed to the same standard as those containing new material.

It must be borne in mind that these conclusions are based on results from only one road trial albeit supported by an extensive programme of laboratory testing. Overall there seems to be sufficient evidence to begin using the off-site recycling technique provided careful control and testing of the reclaimed material is carried out. In early applications of off-site recycling it would be prudent to carry out performance related measurements on the materials and on the road to give an indication of the anticipated longterm performance.

9. ACKNOWLEDGEMENTS

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APPENDIX A: PROCEDURE FOR PRODUCTION OF RECYCLED MATERIAL

A procedure for selecting the composition of the virgin material for inclusion with reclaimed material, to produce a recycled mix complying with a British Standard specification is given as a flow chart in Figure A1.

The penetration (P) of the added bitumen required to soften the reclaimed bitumen to bring the blend within the specification is given as,

$$P = (P_{ry} / P_{rm}^{a})^{1/b}$$

where a and b are the proportions of old and new bitumen such that a+b=1,

P_{ry} is the penetration of the bitumen in the recycled mix

P_{rm} is the penetration of the bitumen in the reclaimed material.

Any reclaimed material containing tar should be rejected.

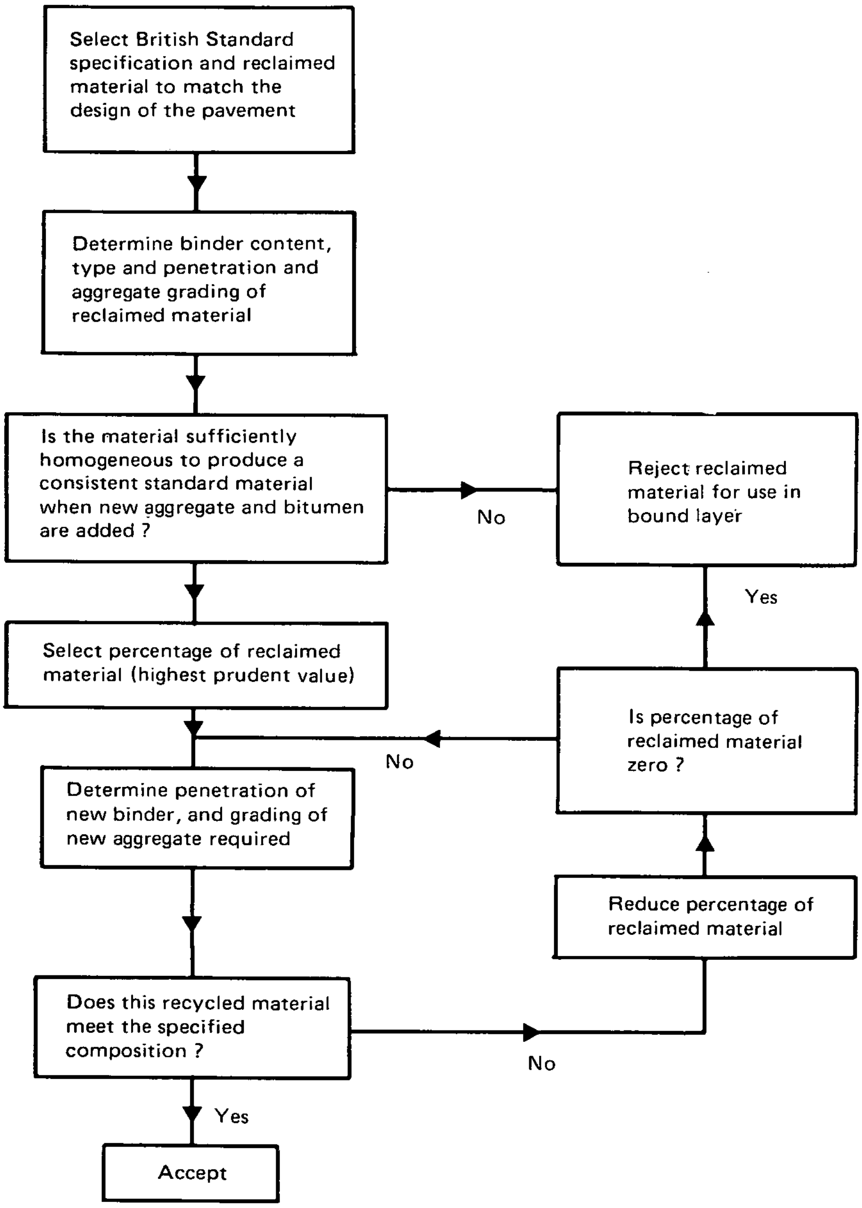

Fig. A1 Procedure for production of recycled material

APPENDIX B: SMIX/SBIT CHARACTERISTICS OBTAINED FROM CREEP-TESTS

The deformation resistance, expressed as 'mix stiffness', is dependent on the temperature of the test and the loading time. Any differences in mix stiffness between different materials could also be produced by differences in the viscosity of the bitumen. The deformation resistance of a mix can be characterised independently of test conditions by the relationship between 'mix stiffness' (Smix) and 'binder stiffness' (Sbit). The procedure to determine the stiffness of the bitumen (Sbit) is given in the British Standard Draft for Development DD 185 (British Standards Institution, 1990). In practice it is obtained from Van der Poel's nomograph (1954) using the penetration and softening point values of the binder obtained from the test specimens. The bitumen stiffness (Sbit) is determined at equivalent loading times as the mix stiffness (Smix).

Figure B1 gives the mean Smix/Sbit for the DBM materials from the pilot-scale trial. It shows that the stiffness of the recycled DBM materials is similar to that of the virgin material and that all the DBM materials are stable when the stiffness of the bitumen is low.

Figure B2 gives the mean Smix/Sbit relationships for the recycled and conventional material from the full-scale trial (omitting Section 4 from the 0 per cent roadbase). The result from Section 4 is not included in the mean value for the conventional material and is shown separately. From these graphs it is evident that at a given bitumen stiffness the recycled HRA mixes are less stiff than virgin material. The differences were not due to the variation in binder stiffness but due to an inherent difference in the mixes themselves. This difference cannot be attributed to aggregate grading or binder content as these are almost identical, neither can it be due to an increased filler content as this would tend to stiffen mixes. Construction practice and compaction were also identical. Unlike dense macadams where the deformation resistance is derived from the mechanical interlock of the continuously graded aggregate, HRA, with gap-graded aggregate, derives most of its deformation resistance from the properties of the fine aggregate/bitumen mortar. When mixing material containing reclaim, 'new' bitumen could merely coat the 'old' bitumen covering the reclaimed material. This heterogeneous coating with a lower

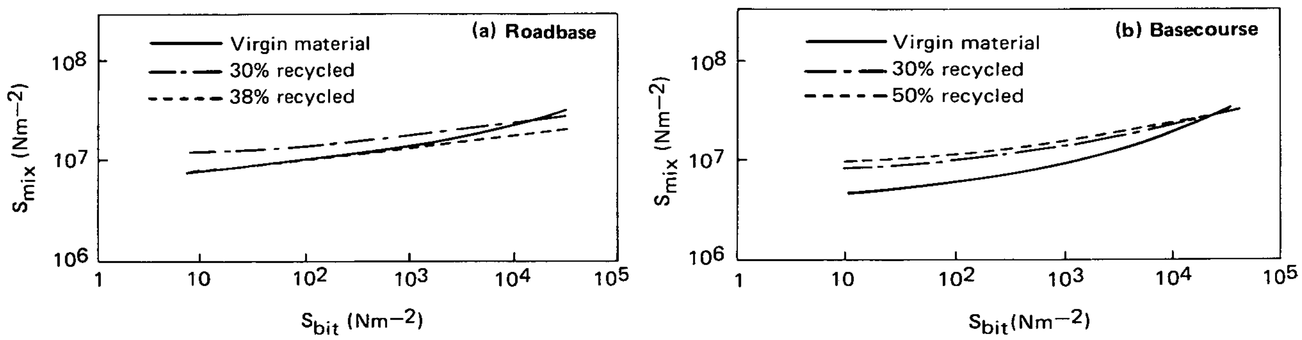

Fig. B1 Relationship between mix stiffness and bitumen stiffness for DBM roadbase and basecourse laid in the pilot-scale trial

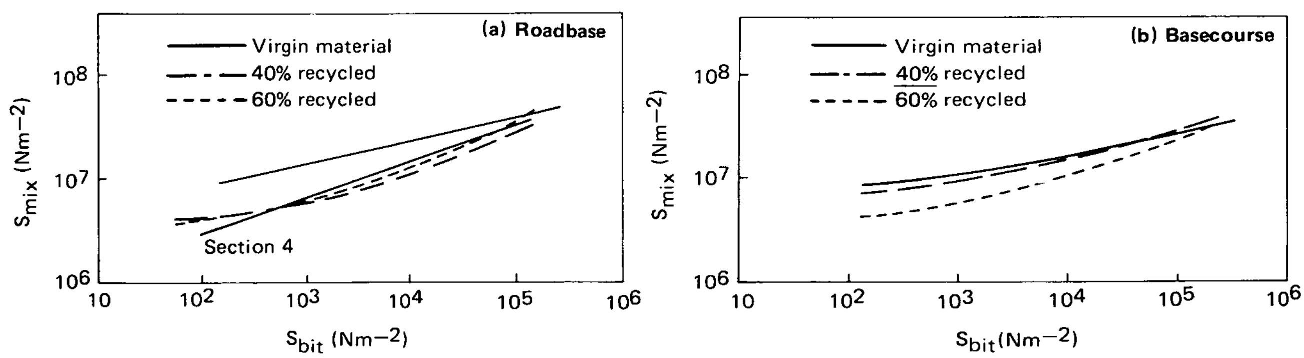

Fig. B2 Relationship between mix stiffness and bitumen stiffness for HRA roadbase and basecourse laid in the full-scale trial

viscosity outer shell would be expected to reduce the creep stiffness of HRA more than DBM because of the relative contribution of aggregate interlock in the two materials. However, it would be expected that in the pavement the binder should homogenise with time. Another factor is one affecting the fines/binder mortar in HRA's in that the reclaimed material could contain low stability fines, eg. rounded sand rather than crushed. Fine aggregate shape and texture have been shown to influence creep behaviour (Hills, 1973). Therefore, the type of material as well as the grading should be taken into account when selecting material for inclusion in recycled mixes. However, Figure B2 shows that, with the exception of Section 4, all the curves level out at low bitumen stiffness which indicates that the recycled rolled asphalt roadbase materials are stable at high temperatures and at long times of loading. In contrast the graph for the virgin roadbase material laid in Section 4 shows no tendency to level out, indicating relative instability.

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