Feasibility of recycling surfacing materials back into thin surfacing systems

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ABSTRACT: Proprietary thin asphalt surfacing systems were first introduced into the United Kingdom in 1991. The need to recycle thin surfacing systems is more critical than with many other generic surfacing materials because of the quantity of relatively scarce aggregates with high skid-resistance properties within the layer. Laboratory investigations and site trials have been successfully undertaken. The trials were on the access to an asphalt plant and on two heavily trafficked sites on the Highways Agency road network, and included the use of polymer modified binders (PMBs) and up to 30 % reclaimed asphalt (RA) in the mixed asphalt. The trials demonstrate that 10 % RA can be easily added to new materials without affecting grading. As the proportion of RA increases up to 30 %, greater care needs to be taken on assessing grading compatibility and how to treat the residual binder present in the RA as a proportion of the 'active' binder content in the recycled surface course layer.

1 INTRODUCTION

Traditional asphalt surface course layers for major roads have generally been laid at least 40 mm thick. Thinner surface course materials have been available, but were considered to be technically inferior and they were only used on roads carrying low traffic levels within the county road networks. However, during the 1990s, various categories of thin surfacing that have beneficial medium term properties have been introduced into the United Kingdom, mostly from the continent. Thin asphalt surfacing systems have now gained a major share of the surface course market in all parts of the network because of these properties (reduced noise, reduced spray, and improved deformation resistance).

There are several categories of thin surfacing systems (Laws, 1998) with marked differences between these categories, with only some of them being thin hot-mix materials. For the purpose of the initial feasibility study into recycling thin surfacings back into thin surfacing systems, only two categories of material were considered in order to develop a focussed and thorough research plan. The two categories are thin stone mastic asphalt (TSMA) with fibres as an additive and thin asphalt concrete (TAC) surfacing systems with polymer-modified bitumen (PMB) because these were considered the materials most likely to provide options for recycling in the near future. As at September 2006, there were 38 proprietary thin surfacing systems manufactured with either PMB or fibres that were named on 28 Highway Authorities Product Approval Scheme Roads and Bridges certificates issued by the British Board of Agrément.

There is a range of PMBs on the market for the different surfacings, which could be a constraint to recycling these materials back into other systems. The PMBs supplied by manufacturers can vary in their chemical make-up and, therefore, may not necessarily be compatible with each other. The results of attempting to rejuvenate an aged PMB supplied by one supplier with a fresh PMB supplied by a different supplier were unknown and required investigation before it could be attempted in situ. Otherwise, there could be a detrimental effect on the durability and performance of the surfacing system. With five major suppliers of PMBs, there are more than fifty possible permutations of aged and unaged binders. Hence, recycling of thin surfacing systems with PMBs needed to be investigated at laboratory scale before full-scale application could be undertaken.

Consideration should be given to making the most efficient use of the materials that will increasingly become available when these materials are planed off because the initial sites laid with thin asphalt surfacing systems in the United Kingdom are reaching their expected serviceability life (Nicholls et al., 2002). The need for such consideration with the thin hot-mix materials is exacerbated because of the greater use of high quality aggregate (that is, with high polished stone values) in these materials than occurs with surface dressing or the application of pre-coated chippings to hot rolled asphalt. Aggregates with high polished stone values are a finite resource that is becoming relatively scarce. Therefore, the Highways Agency commissioned the Transport Research Laboratory (TRL), in collaboration with Lafarge Aggregates Limited (Lafarge), Scott Wilson Pavement Engineering (SWPE) and Shell Bitumen (Shell), to investigate the feasibility of recycling materials from thin surfacing systems back into thin surfacing systems (Carswell et al., 2005) .

2 AGGREGATE DEGRADATION

Changes in Properties

The properties of the recycled aggregate should reflect those of the original material and, hence, depend on the requirements for the site and pavement layer for which the asphalt was designed. In general, the recovered aggregate properties measured from a recovered SMA (flakiness index, elongation index, oven dried density, saturated surface-dry density, apparent particle density, water absorption, aggregate crushing value, dry 10 % fines value, soaked 10 % fines value, dry aggregate impact value, soaked aggregate impact value, aggregate abrasion value, polished stone value, magnesium sulphate soundness value, Micro Deval coefficient and Los Angeles coefficient) compared well with original test data for the same aggregate although the measured densities, water absorption and dry aggregate impact values tended to be slightly lower than for the original material. These differences suggest there may have been variability in the samples supplied to each laboratory and/or an operator effect on the results. Porous asphalt (PA) from the M40 between junctions 5 and 7 was laid during 1994 with some areas planed off in 2001. Again, the recovered aggregate properties measured from a recovered PA compared well with original test data for the same aggregate.

Some of the differences that were evident in both the SMA and PA may be explained by the variability in the aggregate properties and testing error. However, the similarities do indicate that the suitability of an aggregate can be assessed from either prior knowledge of the component materials or by testing samples, of sufficient quantity, of the recovered aggregate. The only property, other than particle size distribution, that theoretically might change is the absorption because the initial binder coating could clog the pores. However, this observation is general to recycling any asphalt rather than being specific to recycling other asphalt materials into thin surfacings.

Changes in Composition

The initial analysis results showed an unexpected difference in the binder contents found by the three laboratories involved. The binder contents were analysed by all laboratories using the rolling bottle method in accordance with BS 598-102 (BSI, 1996), but one laboratory had included an additional step of leaving the sample and solvent to stand for 90 min in the metal bottle before rolling. The difference in the results showed that, on average, the standing allowed over 1 % of additional binder to be extracted from the sample.

Analyses were carried out on both the as-received aggregate and after the binder had been recovered, with noticeable differences. In particular, the gradation of the “as received” reclaimed asphalt (RA) included material retained on the 20 mm and 28 mm sieves due to clumps of aggregate and binder being present. The gradings after binder recovery from all the laboratories were broadly comparable and were close to or near to the finer end of the grading envelope indicating that the grading may have become slightly finer with planing.

Theoretical Maximum Proportion

Suitable gradings of the final mixtures, combining the RA with virgin aggregate, are required in order to ascertain whether the gradings obtained from RA are suitable for manufacturing thin surfacings without separation into fractions. For this exercise, two gradings each of two types were used; a thin asphalt concrete system and a stone mastic asphalt with both 10 mm and 14 mm nominal maximum size aggregate. The grading for stone mastic asphalt used here is the generic grading for the material given in TRL Report PR 65 (Nunn, 1994). There is no equivalent “generic” grading for thin asphalt concrete systems and there can be significant differences between different proprietary products. The grading for a proprietary 14 mm TAC from Lafarge was selected, as they were a partner in this project.

In order to compare a RA grading with a target grading, the fractions between pairs of sieves were calculated for both gradings using the same size sieves for both materials. The method used is described fully in the full report on this work (Carswell et al., 2005). However, such limits are calculated without reference to the variability within the RA grading. Therefore, the limits found have to be tightened and/or the proportion of RA reduced in order to allow for the natural variability that will occur in the RA grading.

The maximum theoretical proportions of RA found by three laboratories to be capable of incorporation into a thin surfacing system are shown in Table 1.

Table 1: Maximum theoretical proportions of RA

Material	Lab.	14 mm TAC	14 mm TSMA
20 mm porous asphalt	Lafarge	25 %	25 %
	LincsLab	35 %	47 %
20 mm hot rolled asphalt pre-coated chippings	Lafarge	16 %	16 %
14 mm stone mastic asphalt	Lafarge	74 %	83 %
	LincsLab	68 %	89 %
	Shell	68 %	51 %

The values assume that the gradings of the recycled aggregate are known and remain constant, which is not the case. In practice, an envelope for the RA would be needed which, in turn, would require a more complex analysis to derive the maximum proportion to be added and the envelope of the virgin aggregate in order to maintain the limits on the final grading.

From these results, it appears that 20 mm nominal size aggregate mixture RA can generally be recycled without first splitting the material into separate fractions for use in 14 mm nominal size mixtures, although it was found they cannot be recycled into 10 mm nominal size mixtures because there will be particles retained on the 14 mm sieve. Top screening to remove that oversize material could easily be carried out, but it is an additional task with an associated cost.

Nevertheless, it would appear that RA could easily be used in gradings one size smaller, but not two sizes smaller. For this purpose, "smaller" implies the next sieve size down in a standard aggregate grading, which are generally set to give a ratio of at least 1.4 between adjacent sieves. It is assumed that they can be used in mixtures with the same nominal maximum size, but that the maximum theoretical proportion will be affected if either the grading is very dissimilar or there has been significant degradation in particle size during planing.

The values of the maximum theoretical proportion of RA (other than from SMA) ranged from 16 % to nearly 50 %, but the minimum value was in excess of that which many plants can accommodate. Therefore, the reduction of these values to accommodate uncertainties in the RA grading would not present problems at typical proportions for recycling. However, there will be a need to use higher levels of recycling in order to maximise this aspect of sustainability, and these higher levels will require further research and investment in plant.

3 RESIDUAL BINDER

Proportion Recovered

Factors such as surface wear, binder hardening and, in the case of porous surfacings, build-up of detritus within the layer will all have an impact on the percentage of binder recoverable from the RA mixture.

Recovered Binder Properties

The binder properties of recovered SMA indicated a significant hardening since the material was originally mixed, as would be expected. Given such hardening, a decision needs to be made as to whether all or part of the original binder can be "rejuvenated" and reused in the new material as binder, with the remainder being treated as being so hard that it is effectively aggregate or 'black rock'.

A test programme was carried out on the binder recovered from PA on the M4 contracts laid in 1993 and 1994, with a summary of the results in Table 2.

As with the physical properties of the aggregate, consideration of binder properties applies to recycling any asphalt mixture, whether or not it is into a thin surfacing system. The only effect of it being into a thin surfacing system is that the quality control may need to be tighter. Furthermore, how the residual binder is treated within a new mixture, in terms of additional binder required, will depend upon the proportion of RA to be added to the mixture.

The 'activity' of the residual binder is presumed to be related to its properties, which have traditionally been related to recovered penetration, and a 'critical limit' of 15 dmm (Daines, 1994) has been considered to be the failure criterion for unmodified binders in PA. However, this assumption requires further investigation because there are reports in the literature of successful recycling of RA with lower recovered penetrations.

Table 2: Binders as supplied to, and recovered from, the M4 PA contracts

Test Results	Initial	1994	1995	1996	1997	1998	2000	2004
1993 Contract (Junction 33/34)								
Pen @ 25 °C (0.1 mm)	98†	68	44	26	23	22	18	–
Pen @ 5 °C * (0.1 mm)	–	–	–	18	18	17	12	–
Softening Point (°C)	–	52.4	54.6	63.2	65.0	67.0	70.2	–
Ductility @ 5 °C (mm)	–	–	–	32	6	5	5	–
1994 Contract (Junction 32/33)								
Pen @ 25 °C (0.1 mm)	103†	97	53	33	26	25	20	14
Pen @ 5 °C * (0.1 mm)	–	–	–	23	19	16	13	8
Softening Point (°C)	–	48.2	51.2	57.0	59.6	62.2	63.8	69.0
Ductility @ 5 °C (mm)	–	–	–	32	13	5	6	4

* = 200 g, 60 s † = avg. pen obtained on supplies to the contract

Although the technical issues associated with recycling a small proportion of PMB modified thin surfacing (say 15 %) back into a new thin surfacing were currently unknown, it was considered that binder drainage (in association with composition, for completeness) would be a useful measure of the compatibility between the recycled and virgin PMB material. Trials were undertaken that showed even with different old and new PMBs, there were no binder drainage problems.

The properties and quantity of the new binder required to rejuvenate a RA binder will depend upon the recovered binder properties and amount of binder present in the RA and the quantity of RA to be added to the mixture.

4 TRIALS

Renishaw Trial

On 24 June 2002, pilot scale trials of SMA incorporating RA from the A50 Doveridge were carried out on the access road to Lafarge's Renishaw Asphalt Plant near Sheffield. Three trial panels were constructed, of which one comprised a control (SMA without RA) whilst two further trial panels incorporated 15 % and 30 % RA, respectively.

The existing surface course was profile planed and a polymer modified emulsion tack coat applied prior to laying the SMA surface course. The mixing times for the material in the asphalt plant was 60 s for all three mixtures although the normal mixing time for SMA at the plant is 40 s. The additional mixing time was added as a precaution to ensure thorough mixing of the RA with the virgin material.

Particle gradings and binder contents were carried out in accordance with BS 598-102 (BSI, 1996). The additional 90 min standing time did not appear to influence the determined binder content for samples up to and including those containing 30 % RA in any consistent manner. For the grading design of the SMA mixtures incorporating RA, the mean SMA RA gradings were used to determine a required grading envelope for the maximum virgin aggregate to be added. The combined recycled mixture had to comply with the specification limits suggested in the Appendix to TRL Report PR 65 (Nunn, 1994) for 14 mm SMA.

Cores were extracted shortly after construction in each of the trial sections for wheel-tracking assessment at 60 ºC to BS 598 Part 110 (BSI, 1998). The results indicated a slight increase in wheel-tracking rate with increasing RA content; 1.5 mm/h for the control and 2.2 mm/h for the 30 % RA sections. However, the binder content measurements were also higher in the RA sections, and these higher binder contents are the more probable cause of variations in measured wheel-tracking rate rather than the addition of RA itself.

A1(M) Hatfield Trial

The site is located in Lane 1 of the northbound carriageway between J3 and J4 on the A1(M) in Hertfordshire. The trial consisted of four sections comprising two controls and two sections with 10 % RA. Two sources of planings were used in the trial, pre-coated chippings (PCC) from hot rolled asphalt (HRA) and SMA.

The PCC planings were obtained from the A10 in Hertfordshire by planing off the top 20 mm of the HRA surface course to maximise the 20 mm aggregate content; that is, this layer will contain all the 20 mm rolled-in PCC. Grading analysis indicated that only a maximum of about 16 % recovered PCC could be incorporated into a 14 mm SMA, but the variation in the RA grading would reduce that proportion in practice and, at 16 %, it may then push the material to the edge of the grading envelope. Therefore, without further processing, such material would be more suitable for a 20 mm SMA, where a theoretical maximum of 60 % could be added and this material was used as the 10 % RA content for a generic 20 mm SMA.

The 14 mm SMA type thin surface course planings were obtained from A50 Doveridge, as for the Renishaw trial, and these were used as the RA content for a 14 mm SMA. Higher levels of RA were not possible on this trial due to the limited availability of the RA and the capability of the asphalt plant used at Hoddesden.

Laying of the trial took place during a nightshift in January 2004, and 50 mm of existing surface course was planed out and replaced with 50 mm of thin surfacing material. After planning, the surface was swept and tack coated with polymer modified bitumen emulsion. Air temperature and surface temperature measurements were +2 °C and +2 °C, respectively, at 23:00 h and +1 °C and 0 °C, respectively, at 04:30 h. Wind speed measurements were below 8 km/h at 23:00 h and 04:30 h. The mixing times for both the control and RA mixtures were kept constant at 55 s.

Site testing during the works included measurements of the texture depth by the patch method (CEN, 2002) and density by a nuclear density gauge (NDG) together with taking bulk samples for subsequent measurement in the laboratory of the grading, binder content and maximum density. Further survey work during a night-time closure on 31 July 2004 included a visual survey and extraction of cores. Three 150 mm diameter cores were taken from each section for density scanning followed by binder recovery testing of the surface course layer. Similarly, three 200 mm diameter cores were taken from each section for wheel tracking at 60 ºC. The visual survey showed all sections to be in good condition with no cracking, aggregate loss, or fatting up noted in any of the sections.

The material grading and binder content were shown to be compliant with the proprietary specification. The penetration and softening point analysis of recovered binder from loose material taken at site and cores extracted later showed no discernable differences between tests or any variation between the control and RA sections. Similarly, wheel tracking at 60 ºC showed little or no differences in tracking rate between control and RA sections for the same size material. The binder contents for each of the sections were also similar.

A405 Bricket Wood Trial

The trial is located in Lane 1 of the northbound carriageway of the North Orbital Road, Bricket Wood linking J6 of the M1 at the southern end to J21a of the M25 at the northern end. The trial included control, 10 % and 30 % RA sections of both the proprietary TAC and TSMA materials. The RA was sourced from PA planings from the M4 Cardiff which contained a modified binder. The modified binder utilised in the TAC variants was from a different source to that used in the original PA.

The trial was constructed during a nightshift on 23/24 August 2004 after a period of heavy rainfall during the day of the 23 August. The asphalt mixing plant was located at Harper Lane near Radlett and this enabled the addition of 30 % RA to be added to the virgin mixture. 50 mm of existing surface course was planed out and replaced with the same nominal thickness of thin asphalt surfacing. The tack coat applied was a proprietary polymer-modified product.

On site measurements and sampling during and after construction were undertaken to measure the texture depth by the patch method (CEN, 2002) and the density using a nuclear density gauge, and to determine the grading and binder content in the laboratory. A visual survey during construction showed that there was standing water in places, including the verge and other locations across the carriageway. Subsequent to the works, in October 2004, a detailed visual survey was undertaken of the finished works during a day time off peak closure. This survey showed there to be areas of fatting up in each of the three SMA sections. Grading and binder content measurements complied with the specification and it is thought that the presence of high levels of moisture along the site during laying was responsible for the areas of fatting up.

Three 150 mm and three 200 mm diameter cores were extracted from each of the six trial sections for binder recovery analysis and wheel-tracking assessment. Gradings including filler and binder content were all found to be within the specification limits for the material. Wheel-tracking results (mean of 3 samples) at 60 °C were similar for the thin surfacing sections ranging from 0.7 mm/h in the control to 1.1 mm/h in the 10 % RA section (0.8 mm/h in the 30 % RA section). For the SMA sections, the results showed the control and 10 % RA sections to be similar at 1.3 mm/h and 1.2 mm/h respectively. However, the results from the 30 % RA section showed a mean tracking rate of 3 mm/h although this was for two samples only and would need to be repeated to confirm the increased rate or rutting measured compared with other sections. The recovered binder penetration and softening point for the SMA section showed no variation in value that would indicate the material to be more prone to deformation and, furthermore, there was little variation in measured binder content. The penetration and softening point measurements on the *TAC* materials showed a reduction with increasing proportion of RA in the mixture falling from 93 pen for the control to 66 pen for the 30 % RA mixtures.

Additional binder testing was carried out on the binder recovered from Section 3 (*Cariphalte TAC* incorporating 30 % RA with another PMB). The polymer content of the recovered *Cariphalte* with another PMB was found to be 85 % of the expected amount and this loss may be a function of the amount of polymer obtained from the recovery process (that is, unrelated to the mixing of PMBs). The binder recovered from the TAC with 30 % RA PMB appears to be slightly stiffer than that recovered from the control TAC material. However, the dynamic shear rheometer master curves for the two recovered binders showed little difference between them so that little difference in mixture durability would be expected in the mixed asphalt.

5 CONCLUSIONS

The site and laboratory trials have shown that it is feasible to recycle thin asphalt surfacings into new thin surfacings with the addition of up to 30 % RA if the plant has the capability to add that proportion of planings.

Laboratory investigation of different mixtures indicated that aggregate suitability can be assessed from prior knowledge or testing of recovered aggregate. Grading of recovered aggregate showed that the maximum theoretical amounts that may be recycled into new mixes may be constrained by individual asphalt plant capabilities.

The constraints on wider use of recycling are that not all asphalt plants are capable of adding 30 % RA, and that a more stringent testing approach than normal needs to be adopted when increasing the amount of RA to be added to the mixture, particularly in terms of how to treat the residual binder.

Significant binder ageing has been observed in binder recovered from SMA and PA RA. This ageing has raised the question of how much of the binder is 'active' and needs to be considered in the new mix and how much is 'in-active' and acts as a 'black rock'.

Three full scale trials have been successfully carried out with up to 30 % reclaimed asphalt.

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