Recycled asphalt in surfacing materials: a case study of carbon dioxide emission savings

by I Schiavi, I Carswell and M Wayman
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RECYCLED ASPHALT IN SURFACING MATERIALS: A CASE STUDY OF CARBON DIOXIDE EMISSION SAVINGS

Version: Final

by I Schiavi, I Carswell and M Wayman (TRL Limited)

Prepared for: M25 Sphere: M25/SW/2867
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(Steve Smith)

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Executive summary

This report documents a study on the energy used and relative carbon dioxide emissions associated with the recent resurfacing of the M25 Junction 6 to 7 Reigate Hill scheme. This study aimed at understanding the potential savings in energy and carbon dioxide realised by the choice of high recycled content material as opposed to a comparable conventional 100% virgin aggregate mixture. The activities undertaken during the resurfacing works were therefore audited and compared with an hypothetical scenario where the conventional material would have been laid.

The resurfacing works, carried out during August 2007, replaced the worn out Porous Asphalt surface course with a thin surfacing to Clause 942 of the Manual of Contract documents for Highway Works (MCHW). The new material laid was developed by Tarmac at the request of Mouchel Parkman, and contains up to 23% of asphalt planed from the existing worn out surface. A control section of MasterPave was laid in order to obtain sufficient quantities of reclaimed asphalt to undertake a mixture design for the MasterPave-R. This high recycled content material has been named 14 mm MasterPave-R thin surfacing system, this being a variant of Tarmac’s 14 mm MasterPave BBA HAPAS certified thin surfacing system.

The energy and carbon emissions audit undertaken follows a Process Analysis methodology. This is a “bottom-up” approach that considers all activities related to a product or within an organisation, as included within a set of boundaries. This approach is the basis of the Publicly Available Specification PAS 2050 on carbon footprinting currently being developed by the Carbon Trust and the British Standard Institution and underlines the current BS ISO standards on greenhouse gases emissions accounting (BS ISO 14064).

The steps followed within the methodology are:

- Definition of boundaries and processes to be included and excluded;
- Collection of data and calculations and
- Internal verification.

Processes included are transport of raw materials and bitumen bound materials to and from the site; production of input materials (e.g. bitumen, aggregates, fibres) and mixtures (both MasterPave-R and MasterPave), use of primary and ancillary equipment, for heating, mixing, loading, paving etc.

A data collection template listing all activities to be considered was prepared and data gathered on quantities and type of energy used and distances travelled by which mode. This required a considerable effort from the supply chain, mainly the material provider Tarmac, to retrieve all information from a number of sources. All data for the actual scheme and for the alternative scenario were input into a custom built spreadsheet for the calculations of the energy and CO2 emissions associated and relative savings.

The principal findings from this study, summarised below, show that savings of just over 16 tonnes of CO2 (about 7% reduction) and just under 253 GJ of energy were achieved by using MasterPave-R (with 23% reclaimed asphalt) when compared with a conventional approach using 100% virgin aggregates for this particular scheme. This saving is equivalent to the emissions produced by an average car travelling over 97,500km (about 60,900 miles) or to the energy that would keep 70 typical 250W motorway lights on for their entire average 4,000 hour life.

Summary of energy and CO2 savings

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>Savings realised by the scheme as compared to alternative MasterPave construction:</td>
<td>252.73 GJ of energy</td>
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<td></td>
<td>70 lights</td>
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</table>
1 Introduction

The need for sustainable construction processes and to conserve natural resources is well understood and recognized within the industry. The M25 Reigate hill was surfaced in porous asphalt in 1996 and this had now reached the end of its serviceable life. Following studies undertaken by TRL (Carswell et al., 2005), Mouchel Parkman sought to incorporate a proportion of the existing surface course layer into a new surface course system, thus maintaining the ‘high value’ application of the high polished stone value (psv) aggregate present in the existing surfacing. For this scheme, the energy consumed by each part of the process was evaluated to gain an understanding of its impact on the carbon footprint when reclaimed asphalt (RA) is incorporated into the new thin surface course (TSC) compared with a TSC containing 100% virgin aggregate. This included taking into account transport of virgin materials and RA (aggregates, filler, fibres, and binder) from source to site; and processing of materials (planing, screening, mixing, paving, and compaction). The comparisons made are specific for this scheme, as the geographical location of the site, source aggregates and transport modes will be unique for every site.

This report documents the details of the scheme, the methodology followed for the audit and the headline results.
2 Background

Proprietary thin asphalt surfacing systems were first introduced into the United Kingdom in 1991 and many of the early sites are now reaching the end of their serviceable lives. 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 of have been undertaken and trial sites have been successfully constructed with up to 30% reclaimed asphalt (RA) in the mixed asphalt (Carswell et al., 2005). A scheme was also completed in 2006 on the M4 Cardiff where 25% of the existing porous asphalt (PA) was processed and incorporated into the new asphalt surface course (Nicholls et al., 2007). Whilst the process itself has been shown to be feasible, previous work has not included monitoring of the energy consumption to establish the relative carbon footprint of using RA compared with 100% virgin aggregate. It is recognized that the carbon footprint will depend on both the processes used and geographical location of the scheme.

TRL has undertaken research in the past to measure the carbon dioxide emissions associated with road construction and road resurfacing works. The ‘CO2 Estimator Tool’ was developed in a research project conducted for the Waste and Resources Action Programme (WRAP) (C4S at TRL Limited, Taylor Woodrow Technology and Costain Limited, 2006). The tool enables the user to evaluate the relative CO2 savings of using alternative road construction materials (secondary and recycled) against traditional virgin materials. The tool is based on a Life Cycle Inventory methodology, which is currently used as the methodological reference for carbon footprinting standardisation (PAS 2050:2008, BSI, draft 2007) and uses information taken from literature and technical specifications for materials and equipment to build a database of parameters and default data. Furthermore, C4S has also completed a full carbon footprint study was completed for an innovative cold mixing asphalt system, evaluating the benefits of its use against hot mixed asphalt (C4S at TRL, 2006).

The value of undertaking studies on energy and carbon emissions associated with construction projects and products is clear in light of the current drive towards a low carbon economy and the Government commitment to reduce carbon emissions. Understanding how much energy is used to provide certain goods or services is the first step towards taking action on improving energy efficiency, thus reducing environmental impacts and realising cost savings. This is also true of other environmental impacts, e.g. efficient use of natural resources through waste minimisation, reusing and recycling.
3 Scheme details

Four continuous segments of the M25 clockwise carriageway surface between Junctions 6 and 7, MP 43/2 and MP 47/3 were identified as requiring treatment. Traffic flows on this carriageway were reported in 2005 to be 73,497 AAWT (average annual weekday traffic) and 70,302 AADT (average annual daily traffic) with 14% of this traffic being HGVs. These figures represent a 6% increase on reported flows in 2001.

The scheme location is shown in Figure 2. As built drawings for the works are given in Appendix A of this report.

![Figure 1. Location of scheme](image)

The motorway was originally constructed in 1983, with the current construction consisting of 50 mm PA over 410 mm dense bituminous macadam over 206 mm Type 1 granular layer. There are sections where the PA surfacing has been replaced with thin surface course during maintenance carried out in 2006 between MP 44/6 and MP 45/7. Visual and TRACS surveys of the carriageway identified rut depths of over 10 mm together with fretting and general loss of material.

The proposed treatment was to replace the worn out PA surface course with a thin surfacing to Clause 942 of the Manual of Contract documents for Highway Works (MCHW).

The existing surfacing on Reigate Hill was a 20 mm porous asphalt to BS4987 (BSI, 1993). The aggregates were originally sourced from Bardon Hill (60 psv) in combination with either Ballystockart or Millom (both 68 psv). The planings were processed to remove both the larger and smaller sizes of aggregate by using 16 mm screen and 4 mm screens to effectively give a 2/12 mm usable product compatible with 14 mm thin surface course (TSC). Removal of the fine aggregate sizes also removed any detritus that had built up and reduced the susceptibility of the RA to be used in the new surfacing to moisture.
The initial mix designs incorporating RA were undertaken at Tarmac’s Technical Centre prior to plant trials at Hayes asphalt plant. The plant trials were needed to check production and laying performance together with finished surface texture. Initial trials with all of the RA going into the mix cold were unsuccessful, despite superheating of the virgin aggregate. Further trials showed that target mixture temperatures could be achieved by adding 10% of the RA via the hot elevator and the remainder added cold directly into the mixer.

The RA was incorporated into a 14 mm MasterPave-R thin surfacing system, this being a variant of Tarmac’s 14 mm MasterPave BBA HAPAS certified thin surfacing system.

The works were carried out and completed in August 2007.
4 Energy monitoring

4.1 Methodology

The energy and carbon emissions audit undertaken follows a Process Analysis methodology. This is a “bottom-up” approach that considers all activities related to a product or within an organisation, as included within a set of boundaries. This approach, which is exemplified by environmental accounting methods such as Life Cycle Analysis and Life Cycle Inventories, is also the basis of current ISO standards on greenhouse gases estimation (BS ISO 14064-1:2006, BS ISO 14064-2:2006). Furthermore, the Carbon Trust and the BSI are currently working on a Publicly Available Specification on carbon footprinting (PAS 2050:2008, BSI, draft 2007) which is based on Process Analysis, and current advice from the Carbon Trust is that this approach should be followed for developing carbon audits (Carbon Trust, 2007).

The steps followed within the methodology are listed below and explained in the following sections:

- Definition of boundaries;
- Definition of processes;
- Collection of data;
- Calculations and
- Internal verification.

Care has been taken in ensuring that the method followed at each step is transparent, accurate and consistent, as required within the ISO 14064 standards (BS ISO 14064-1:2006, BS ISO 14064-2:2006). The approach taken within this study is in line with the carbon footprinting methodology published by the Carbon Trust (Carbon Trust, 2007), although only CO$_2$ emissions have been considered, given that the processes analysed deal mainly with combustion of fuel or production of electricity.

4.1.1 Definition of boundaries

The definition of the system to be analysed within an environmental audit is key to the credibility of the audit. The approach taken for this project is based on the “level of control”. That is, the system includes processes from the extraction and transportation of raw materials up to the laying of the material but does not consider, for example, the use of the road by traffic or the manufacture of the equipment. A representation of the system, with some details of the processes included, is given in Figure 2. This was discussed amongst the project team and with Mouchel Parkman at the outset and was detailed during the data collection exercise.

Points of note are:

- The system has a double application: for the MasterPave-$R$ and for a comparative “what if” scenario where a MasterPave (100 % virgin aggregate) mix would be used for the same scheme; details on the differences are provided in section 4.1.2.
- Emissions associated with input materials from third parties have been accounted for by using “embodied” energy and emissions, i.e. quantity of fuel and electricity used to produce the raw materials up to the “gate” of the processing unit (e.g. the factory manufacturing fibres and the refinery producing bitumen). These are overall figures provided by the supplier or sourced from literature, but details are not available about how they have been calculated. This is discussed in more depth in section 4.1.3 below.
- Travel of personnel to and from the site is not accounted for.
Figure 2 Representation of the system and processes

RAP
Natural aggregates
Common processes
data most difficult to source
data most difficult to source
data most difficult to source

1) winning of natural aggregates
2A) disposal/storage of quarry waste/fines
2) crushing/screening
3) transport from quarry to plant
4) heating
A) production of binder
B) transport of binder to plant
C) heating
D) mixing
E) transport from plant to site
F) paving
G) compacting

i) heating
ii) disposal/storage of oversize/undersize
iii) crushing/screening
iv) heating
v) transport from site to plant
vi) planing
4.1.2 Definition of processes

The processes included within the boundaries defined need to be identified. This was agreed with the customer at the outset and further refined during the data collection phase, when more details on the process were provided by the supply chain. The processes included can be grouped by type:

- Transport of:
  - raw materials from factory gate to plant, including asphalt planings from site to plant;
  - MasterPave-R from plant to site;
  - asphalt planings to a site depot, for the “what if” scenario; and
  - planing and paving equipment, which was taken on site every evening and brought back to the depot every morning.

- Production of:
  - input materials from third party supply, i.e. fibres and bitumen – represented by their embodied energy;
  - aggregates at Tarmac’s quarries; and
  - MasterPave-R

- Use of primary and ancillary equipment, such as for:
  - loading and unloading aggregates onto/from trains;
  - planing;
  - laying; and
  - compacting.

4.1.3 Collection of data

A data collection template listing all activities to be considered was prepared and data gathered on quantities and type of energy used and distances hauled using various transport modes. This required a considerable effort from the supply chain, mainly the material provider Tarmac, to retrieve all information from a number of sources. Only a few data were not available from the supply chain and were substituted with the best available information from literature, particularly Life Cycle Analysis studies, Governmental sources and technical specifications.

4.1.4 Calculations

All data for the scheme constructed and for the alternative scenario were inserted in a custom built spreadsheet for the calculations. This calculator was developed using the data found and provided from equipment and materials suppliers.

The following approaches and assumptions applied are of note:

- The ‘number of trips’ is calculated by dividing the tonnage required by the capacity of the transport vehicle. If this is not equivalent to a integer number, energy and emissions are attributed pro-rata and the number of trips is not rounded up to the nearest unit.

- The character of each transport operation was discussed with the Contractor. This was to specifically identify trips where the vehicles were definitely going back empty (e.g. bitumen tankers) and those where the vehicles would continue their trip to other destinations picking up/consigning other materials (e.g. all the transport undertaken by logistics companies, such as the delivery of the fibres to the warehouse). In the former, the full round trip was accounted
for as contributing to energy use and carbon dioxide emissions generation; in the latter, only the trip from the source of materials to the plant or site was accounted for.

4.1.5 Internal verification

The calculation spreadsheet was developed and reviewed by the senior researchers of the team and circulated for internal verification, to ensure data consistency and accuracy of calculations and assumptions. The verification was an iterative process as assumptions taken were discussed until agreement was reached that they represented reality as closely as possible.

4.2 Measurements

Auditing of energy use is a relatively simple, yet time consuming exercise that requires full commitment and buy-in from the supply chain. Tarmac, the material supplier and paving contractor, were fully collaborative and provide very good quality data. Examples of measurements that were required and were provided are:

- mix recipes actually used and energy required for heating and mixing the MasterPave and the MasterPave-R mixes, from the job cards and from monitoring carried on at the Hayes plant;
- energy used for producing different aggregate sizes: this figure came from the quarries supplying the Hayes plant as quantity of energy per tonne of aggregates, deriving from metering of energy consumed in a certain period (month or year) divided by the tonnage of aggregates production in the same period;
- transport and transfer patterns: Tarmac provided a full picture of how the aggregates were moved and transferred between transport modes, the types and capacity of the vehicles used, any back haulage carried out or likely to be carried out;

The models of the equipment used for planing, paving and compacting the materials were either checked during the site visits or ascertained with the supply chain, and information on their power consumption obtained from manufacturers.

Information sourced from literature and used in the calculations included:

- Embodied energy of bitumen (EuroBitume 1999);
- CO₂ emissions factors for electricity, diesel, fuel oil, gas oil (Carbon Trust, 2006);
- Consumption of the Class 66 locomotives, used for transporting aggregates, from a study for the Strategic Railway Authority (AEA Technology, 2001); and
- Boat capacities and emissions, from P&O (P&O, 2007) and DEFRA (Defra, 2005).
5 Findings

The audited resurfacing scheme is estimated to have produced about 220 tonnes of CO₂ and used about 3,235 GJ of energy. Of this, some 192 tonnes of emissions and 2,830 GJ of energy are attributable to the 3,096 tonnes of MasterPave-R laid, with the reminder generated by the 447 tonnes of MasterPave used.

If 3,543 tonnes of MasterPave were used, then it is estimated that over 236 tonnes of CO₂ would have been generated and over 3,488 GJ of energy would have been used.

The savings associated with using MasterPave-R are therefore of the order of just over 16 tonnes of CO₂ and just under 253 GJ of energy. This is equivalent to the emissions produced by an average car travelling over 97,500km (about 60,900 miles) or to the energy that would keep 70 typical 250W motorway lights on for their entire average 4,000 hour life. A summary of the data for the scheme impact and savings are given in Tables 5.1 and 5.2 respectively.

<table>
<thead>
<tr>
<th>Table 5-1 Scheme Impact</th>
<th>Energy used (GJ)</th>
<th>CO₂ Generated (tonnes)</th>
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<tbody>
<tr>
<td>Impact of the scheme</td>
<td>3,235.32</td>
<td>220.02</td>
</tr>
<tr>
<td>of which:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>attributable to MasterPave-R mix (total of 3,096 tonnes</td>
<td>2,828.46</td>
<td>191.97</td>
</tr>
<tr>
<td>used at 22.3% RA content)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>attributable to MasterPave mix used in first section (total</td>
<td>406.86</td>
<td>28.05</td>
</tr>
<tr>
<td>of 447 tonnes used)</td>
<td></td>
<td></td>
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<tr>
<td>Equivalent to approximately, per tonne of asphalt laid</td>
<td>0.913</td>
<td>0.0621</td>
</tr>
<tr>
<td>Impact of the alternative “what if” scenario (only</td>
<td>3,488.05</td>
<td>236.32</td>
</tr>
<tr>
<td>MasterPave used, total of 3,543 tonnes)</td>
<td></td>
<td></td>
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<tr>
<td>Equivalent to approximately, per tonne of MasterPave</td>
<td>0.984</td>
<td>0.067</td>
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<table>
<thead>
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<th>Table 5-2 Scheme savings</th>
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<tbody>
<tr>
<td>Savings realised by the scheme as compared to alternative</td>
<td>252.73 GJ of energy</td>
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<tr>
<td>MasterPave construction:</td>
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<td>70 lights</td>
<td></td>
</tr>
</tbody>
</table>

1 In the UK, the average car owner drives 13,438 km per year, emitting 2.246 tonnes of carbon dioxide. From http://www.carplus.org.uk/carclubs/car-clubs-&-carbon-savings.htm
6 Discussion

It is important to note the following:

- This audit has focused on carbon dioxide emissions only. A full carbon footprint, following the latest guidance from the Carbon Trust and the BSI, should include all greenhouse gases within the ‘basket of six’ agreed upon by the Intergovernmental Panel on Climate Change (IPCC, 1996). However, carbon dioxide accounts for 85% of the greenhouse gases and it is by far the most important greenhouse gas emitted from combustion of fuel.

- The CO₂ figures as normalised to a tonne of MasterPave and MasterPave-R are 0.069 and 0.066 respectively. However, these figures are only relevant to the specific job audited, because they are made up of components strictly dependent on the location and circumstances of the scheme, e.g. distance from the plant, amount of arisings used, mix recipes, equipment type. As a consequence, those figures cannot be used to represent the embedded emissions of the two mixes or the emissions associated when used in other schemes.

- Carbon emissions represent only one indicator of environmental impacts and sustainability.

Overall however it can be seen that the use of recycled asphalt within MasterPave-R has represented a more environmental sustainable solution, from the point of view of carbon dioxide emissions, than a MasterPave would have been in this specific case. To that, the following considerations should also be added:

- use of recycled materials reduces extraction of virgin materials from quarries;
- recycling of surfacing material in surfacing material is a high value application: although recycled asphalt is seldom disposed of, it might often be downgraded;
- due to planings being used in the new material laid, back haulage of the RA from site becomes a practicable option, with an associated reduction of truck movements and, consequently, congestion and cost. For the audited scheme, where the works were carried out at night, the reduction of congestion may not be that significant when compared with day time operations. However, there are effective savings in transport mileage, although these will be dependent on the distance of the plant from the site.

The original aim of adding RA to the new thin surface course was to conserve resources of high psv stone. With the superheating of the aggregate required for the virgin aggregate, when RA is added to the mixture, it was originally anticipated that the process itself would be ‘Carbon neutral’. However, this study has shown that savings in energy and transport can also be realised assuming that the durability of the finished products are comparable. Previous trials (Carswell et al, 2005) have shown comparable performance in the short term. Consistent monitoring of surface course materials with RA is now required to provide this information in the longer term.
7 Conclusions

The project audited a resurfacing scheme where arisings of planed asphalt from a length of the M25 motorway were recycled within the new material laid. The audit considered the energy used and the associated carbon dioxide emissions generated by the manufacturing and placing of the materials as used. An alternative scenario was also analysed where an equivalent, containing 100% virgin materials, bituminous mixture would be used to quantify the savings in energy and emissions realised by the actual construction material used.

It is estimated that the scheme realised savings of about 16 tonnes of CO$_2$ (about 7% saving) and 253 GJ of energy with respect to the alternative scenario. The most savings were realised from the reduction in use of primary aggregates, particularly the 6/14 fraction, and the bitumen. Because of the distance of the plant (57.5 km) from the work site, transport of the mix and the planings from and to the plant required more energy and generated more CO$_2$ emissions than it would have if a MasterPave mix was used and the planings were taken to the depot 16 km away from the site. Further savings would have been realised if 100% of the trucks were always travelling full (of MasterPave from the plant to the site and planings from the site to the plant). Total savings realised by the scheme would have increased to 478 GJ and about 32 t of CO$_2$ if the trucks were always 100% full.

The study has therefore demonstrated that, for this particular scheme, the use of MasterPave-R has realised significant energy and carbon dioxide emissions savings when compared to the use of MasterPave. However, there are theoretically further opportunities for realising savings from improving the back haulage rates.
Acknowledgements

The work described in this report was carried out in the Design and Materials and Resource Management Groups of TRL Limited. The authors are grateful to Miss Emily Townsend, Mr Nick Toy and Mr Tim Smith of Tarmac who provided the data for the calculations, and their colleagues and supply chain partners. The authors are also grateful to Dr Paul Sanders who carried out the quality review and auditing of this report.

References


Appendix A.  M25, J6-7 Scheme: As built drawings
Abstract

The need for sustainable construction processes and to conserve natural resources is well understood and recognized within the industry, and is often realised through recycling materials into layers below the surface course. However, this ‘downgrades’ the use of expensive and increasingly scarce high polished stone value (psv) aggregates. The incorporation of a proportion of an existing surface course layer into a new surface course system is therefore highly desirable as it maintains the ‘high value’ application of the high polished stone value (psv) aggregate remaining present in surface course.

With the reduction in requirement for virgin materials, the inclusion of reclaimed asphalt in the surface course layer may also offer benefits in terms of reduced energy and emissions. This report documents a study on the energy used and relative carbon dioxide emissions associated with the recent resurfacing of the M25 Junction 6 to 7 Reigate Hill scheme. The objectives of the case study were to gain an understanding of the differences and potential savings in energy and carbon dioxide that could be made by the incorporation of a high recycled asphalt content into the surfacing compared with a 100% virgin aggregate mixture. The activities undertaken during the resurfacing works were therefore audited and compared with a hypothetical scenario where the conventional material would have been laid.