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The use of alternative materials in road construction

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ABSTRACT

This paper gives an overview of the collaborative research project Alternative Materials in road construction. The project was part funded by the European Commission and was carried out by a consortium of nine organizations in seven countries. The objective was to develop test methods to assess the suitability of alternative materials in road construction, concentrating on unbound granular applications such as sub-base and capping. The project activities are described and a toolkit of test methods for mechanical, leaching and hydrodynamic properties is presented. Case studies of the performance of alternative materials in roads show that they give as good performance as natural reference materials and have not caused pollution of groundwater. Mitigation measures are discussed and areas for further research identified

INTRODUCTION

Throughout Europe there is pressure to increase the use of alternative materials in construction applications such as roads. This reduces the amount of natural aggregates that have to be used and enables the alternative materials to be used constructively instead of being sent to landfill.

Most European countries have employed economic levers such as taxes on landfill and natural aggregates to encourage the use of alternative materials. Despite these, the extent to which alternative materials are used in road construction is small. This is partly to do with the perception of such materials as being 'waste' and hence inferior; partly for economic reasons such as transport costs; and partly because of concerns about the mechanical and environmental performance of the materials.

ALT-MAT

The Alternative Materials in road construction project was conceived as a way of addressing concerns about the performance of the materials. The project was commissioned by the European Commission under the Fourth Framework Programme and was carried out in 1998 and 1999 by a consortium of nine organizations in seven countries. This gave a Europe-wide perspective on the problem, with a wide range of climatic conditions, alternative and natural materials, and methods of road construction and areas of specialist expertise. The project was co-ordinate by the Transport Research Laboratory in the UK. The other participating countries were Austria, Denmark, Finland, France, Sweden and Switzerland. A list of the participating organizations is given in Section 8.

The main objective of ALT-MAT was to develop methods to assess the suitability of alternative materials for use in road construction, particularly for unbound granular applications such as sub-base and capping. To achieve this, a series of tests was carried out to bridge the gap between laboratory tests and field performance. These included: inspection and monitoring of sections of

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road which had been constructed using alternative materials; lysimeter tests to simulate a road construction without a pavement; climate chamber tests to simulate many years of freezing-thawing and wetting-drying cycles in a few months; and mechanical, leaching and hydrodynamic tests in the laboratory [1].

Materials for testing was selected based on their availability and perceived suitability for use in road construction. Natural reference materials were also tested as a control. The alternative materials tested varied from country to country and included Municipal Solid Waste Incinerator (MSWI) bottom ash, crushed concrete, demolition rubble, steel slag, blast furnace slag and recycling glass.

The main output from the project will be the final report published by the EC. This is currently in draft form. The report will contain a toolkit of methods to assess the mechanical, leaching and hydrodynamic properties of alternative materials, case studies of the performance of the materials in roads, and mitigation measures which can be used if necessary to prevent pollution of groundwater. The results are summarized in the following sections.

TEST METHODS

Mechanical Tests

It was thought that alternative materials might behave in a different way from natural aggregates in standard laboratory tests. An inter-laboratory testing programme was carried out to investigate this. A number of materials including natural aggregates, crushed concrete, MSWI bottom ash, recycling glass and slag were subjected to the Los Angeles and Micro-Deval abrasion tests and the gyratory compaction and vibrating table tests. In the Los Angeles test, the amount of fines produced is measured after 500 revolutions and expressed as a percentage of the sample weight. In the Micro-Deval test, the amount of fines is measured after 12,000 revolutions. To assess the behavior of the materials during the tests, the amount of fines was recorded at intermediate stages: 100 and 250 revolutions for the Los Angeles test; 3,000 and 6,000 revolutions for the Micro-Deval test. The results for the Los Angeles test are shown on Figure 1.

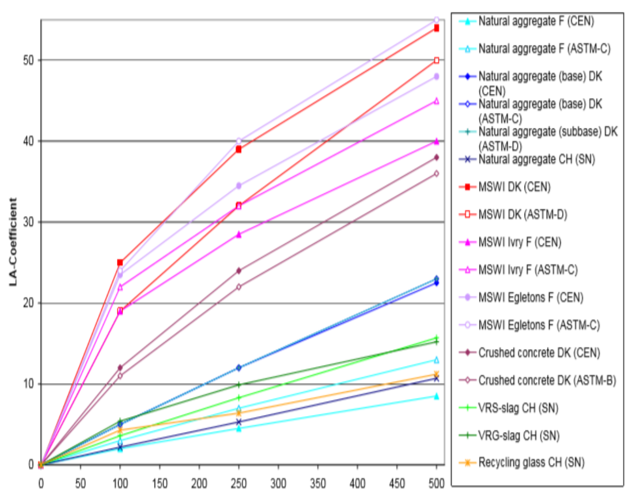

Fig.1 Behaviour of materials during Los Angeles test

The results confirm that alternative materials behave in a different way from natural aggregates. The natural materials behave in a linear fashion, whereas the response of the alternative materials is markedly non-linear, particularly for the MSWI bottom ash, with much greater breakdown of material in the early stages of the test. Crushed concrete occupies an intermediate position. A similar pattern was found in the Micro-Deval tests.

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The alternative materials generally give much higher Los Angeles coefficients than natural aggregates, indicating that they are weaker materials. However, measurements of mechanical performance in the field (section 5) are often much better than would be anticipated from the laboratory results. Design should therefore be based on performance–related tests such as cyclic load triaxial or gyratory compaction. Work is needed to relate these tests to measurements of field performance.

Existing CEN mechanical tests for granular materials were reviewed for their suitability for alternative materials. The following tests are recommended:

- Methods for sampling (EN 932.1)
- Methods for reducing laboratory samples (prEN 932.2)
- Determination of particle size distribution (EN 933.1)
- Determination of the resistance to wear (Micro-
- Deval) (EN 1097.1)
- Methods for the determination of the resistance to fragmentation (EN 1097.2)
- Determination of water content by drying in a ventilated oven (prEN 1097.5)
- Determination of particle density and water absorption (prEN 1097.6)
- Method for determination of loss on ignition (EN 1744.1)
- One of the following test methods for laboratory
- Reference density and water content: standard proctor (prEN 13286.2); vibrio-compression with controlled parameters (prEN 13286.3); vibrating hammer (prEN 13286.4); vibrating table (prEN 13286.5).

Tests using vibration rather than impact are recommended for alternative materials. A test method for the self-binding capacity of alternative materials is needed, as is an improved method to describe the material composition.

Leaching Tests

The leaching behaviour of alternative materials was investigated by a combination of laboratory tests, lysimeter tests and climate chamber tests.

European standardization is less advanced within the field of leaching tests than for mechanical tests. Work is in progress, however, and several CEN tests may be expected to emerge over the next few years. Several of these tests were applied in this project, and the following are recommended for characterization of alternative materials:

- Characterization of waste: Methodology
- Guideline for the determination of the leaching behaviour of waste under specified conditions (draft prENV 12920).
- Column leaching test (NT ENVIR 002).
- Batch compliance tests (prEN 12457-3).

The pH dependency of the leaching behaviour should also be investigated, using a pH-static leaching test. The column and batch tests are carried out with distilled water as the lea chant, so the pH of the leachate is determined by that of the material in a saturated condition. The solubility of many species is pH dependent, so if the pH of the material is likely to change or if it is likely to be exposed to solutions of significantly different pH, then its leaching behavior should be determined at a range of pH values appropriate to the situation.

The purpose of lysimeter and climate chamber tests is to simulate the effect of climate on a road construction without a pavement. Lysimeter are large boxes filled with material and left open to the atmosphere. The drainage water is collected and analyzed. Lysimeters filled with blast furnace slag, MSWI bottom ash and reference materials were already available at the Swedish Geotechnical Institute from earlier experiments. They were restarted and a new lysimeter constructed and filled with crushed concrete.

Climate chamber tests were carried out at the Österreichisches For schungs- und Prufzentrum arsenal in Austria and at the Technical Research Centre of Finland. MSWI ash was investigated in Austria and steel slag in Finland. Twenty freeze-thaw cycles were used in each case.

The results of laboratory leaching tests, lysimeter tests and climate chamber tests are usually plotted as the cumulative amount leached (mg/kg) against the Liquid/Solid (L/S) ratio, as shown in Figure 2. Generally, the lysimeter and climate chamber tests gave similar results to the laboratory tests. The L/S ratio is in effect a time

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axis, and the lysimeter tests allow some calibration. The uncovered Lysimeters at SGI took about 6 years to reach a L/S ratio of 1.0. If the materials were covered by an impermeable layer of asphalt, as in a well-maintained road pavement, it might take ten times longer to reach this L/S ratio. Most laboratory leaching tests are carried out at much higher L/S ratios. Only the column test covers the low L/S ratio conditions likely to be encountered in most roads.

The other major difference between laboratory leaching tests and field behaviour is the effect of exposure to air. Laboratory tests are conducted in a fully saturated condition, whereas in a-road pavement or embankment conditions will be unsaturated for most of the time. A variety of reactions can thus occur in the field, which affects the leachate quality, including oxidation of sulfides, hydration of minerals and carbonation of cement. These reactions affect the pH, and hence leaching tests should be carried out at the pH likely to occur in the field using pH-static tests. It is thus essential to understand the mineralogy of the material and its likely behavior in a road pavement in order to make sensible predictions about its leaching behavior.

The effect of air on a sensitive material is shown by the comparison of the lysimeter results for nickel and pH with laboratory column and batch leaching tests in Figures 2 and 3. The material, air-cooled blast furnace (ACBF) slag contains a small amount of sulfides. Little or no oxidation of the sulfides takes place in the column and batch tests. The pH of the leachate is between 8 and 10 (Figure 3), and the cumulative amount of nickel leached shows a steady increase with increasing L/S ratio from the column tests to the batch test (Figure 2). In the lysimeter, however, oxidation of the sulfides takes place leading to pH values as acidic as 3 at low L/S ratios (Figure 3). This leads to higher concentrations of nickel (and other metals) in the lysimeter leachate than in the laboratory tests, as shown by the higher position of the lysimeter curve on Figure2.

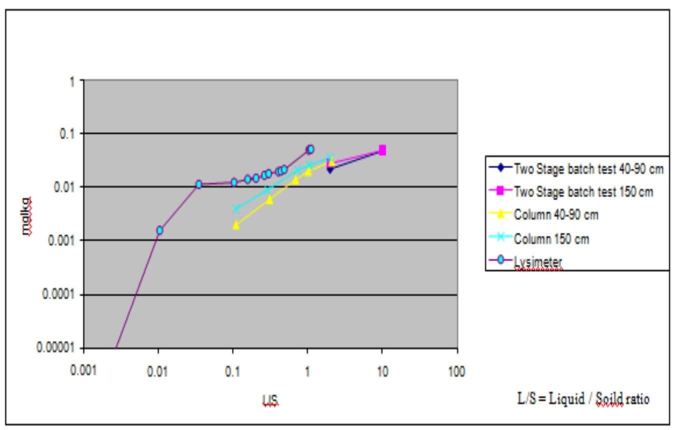

Fig.2 Leached amounts of nickel in the lysimeter column tests and batch tests for ACBF slag.

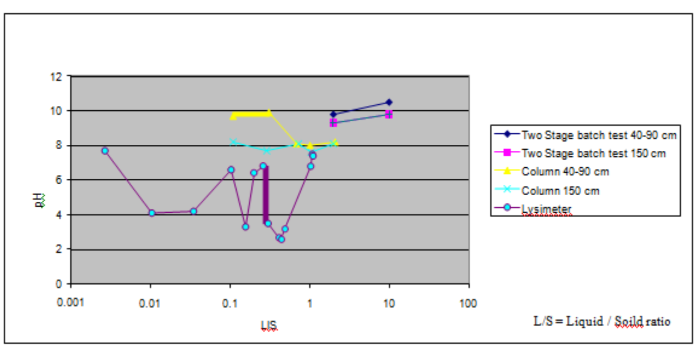

Fig.3 The pH value in the lysimeter, column tests and batch tests for ACBF slag

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A model has been adopted from Hjelmar et al (1999) to predict the impact of leaching from materials in road construction on the quality of groundwater. This utilizes the data from column tests to obtain the cumulative amount leached in a given time period derived from the L/S ratio. It thus reflects the conditions in a road more accurately than leaching tests at high L/S ratios.

It should be noted that the detailed characterization tests such as column and pH-static tests only have to be carried out once on each alternative material. Compliance tests such as the prEN 12457 batch test can be carried out from time to time to check that the composition of the material has not changed significantly. The characterization test results can then be used to assess the suitability of the material for a number of sites, taking into account the site-specific conditions for each site. If the composition of the material changes significantly, further characterization tests may be required.

HYDRODYNAMIC TESTS

In order to measure the movement of water through road constructions, it is necessary to know the relationship between water content and suction, and the relation of both to the hydraulic conductivity. A number of methods are available, all of which are appropriate in certain circumstances. The choice of method is affected by factors such as the electrical conductivity, chemical composition and heterogeneity of the materials. Alternative materials differ markedly from natural materials in this respect, so these properties should be determined at the start of any investigation. Specific calibration curves may be required for some materials, particularly for nuclear methods.

One of the materials which cause problems for electromagnetic measurements of water content is MSWI bottom ash, because of its high electrical conductivity. A new test method was developed for this material at the Laboratories Central des Points Chausses, Nantes, France. The method involved vibrio compression and freezing of samples and use of a pressure chamber for suction measurements. It worked well and is recommended for use in sensitive materials. Two MSWI bottom ashes were investigated, both as fresh and aged materials. The ash behaved like a salty soil, with high water retention even at high suctions (Figure 4). The water content of both ashes increased with age, but the shape of the water retention curves did not change.

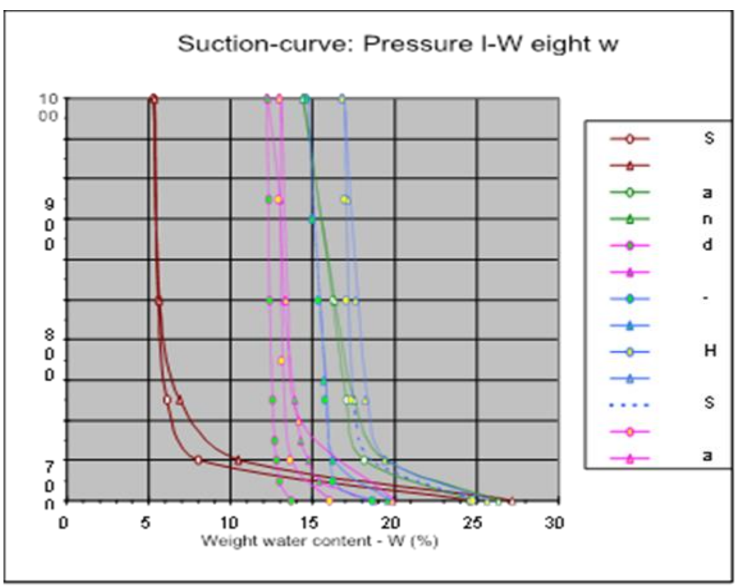

Fig.4 Water retention curves for MSWI bottom ash, sand and silt

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Notes: H = hydration stage
D = dehydration stage
Y = young material (few months)
O = old material (year and a half)

CASE STUDIES

Inspection and monitoring of existing roads was carried out in Sweden, Denmark, the United Kingdom and France, giving a wide range of climatic conditions. The materials investigated included crushed concrete, demolition rubble, MSWI bottom ash, air-cooled blast furnace slag and natural reference materials. The materials were used as unbound granular sub-base and capping. Details of the sites are given in Table 1. Visual inspections and condition surveys were carried out, using Falling Weight Deflectometer (FWD) or Deflectograph tests. Trial pits and trenches were excavated, in-situ tests such as density and plate bearing carried out and samples taken for laboratory analysis. Samples of groundwater were taken for analysis where possible.

Table 1 Inspections of existing roads

Country	**Site**	**Material**	**Subgrade**	**Age (years)**	**CBR (%)**	**E-moduli (Mpa)**
United Kingdom	Bracknell	Demolition rubble	Clay	5	66	999
		Limestone	Clay	5	156	284
Denmark	Skibet Vejle	Crushed concrete	Sand	8	120	540
		Gravel	Sand	8	160	215
Denmark	Skælskør	MSWI bottom ash	Glacial till	5	40	128
		Sand	Glacial till	5	24	180
France	La Teste	MSWI bottom ash	Sand	22	125	nd
France	Le Mans	MSWI bottom ash	Sandy clay	20	110	nd
Sweden	Nyköping	Air-cooled blastfurnace slag	Sand	12	145	600
		Crushed rock	Sand	12	nd	300
Sweden	Helsingborg	Crushed concrete	Clayey till	2	245	850
		Crushed granite	Clayey till	2	nd	300
Sweden	Luleå	Crushed concrete	Silty till	2	nd	870
		Crushed granite	Silty till	2	nd	280

The case studies showed that the alternative materials gave as good and sometimes better support to the pavement than natural reference materials. This is illustrated by the figures for E-moduli in Table 1, which were obtained by FWD measurements. The performance in the field was often better than would have been predicted from standard laboratory tests such as CBR or Los Angeles abrasion value. The CBR values shown are picked from a large number of values. They are mean values at natural moisture content. For crushed concrete and air-cooled blast furnace slag an increase in stiffness with time was recorded, due to the self- binding properties of the material. This is shown in Figure 5 for the Helsingborg site.

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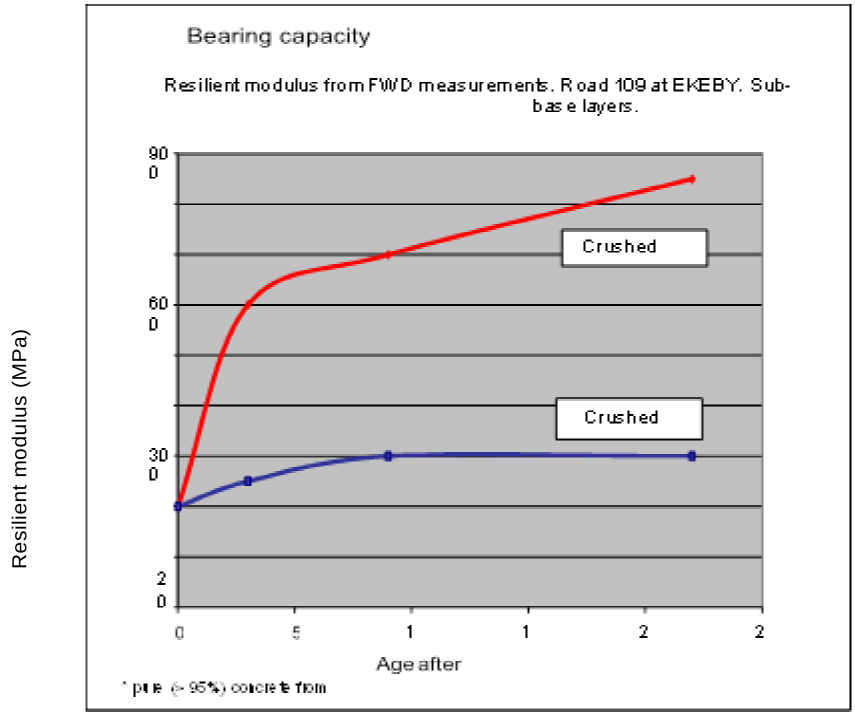

Fig.5 Increase in stiffness with time for crushed concrete sub-base, Sweden

Chemical tests revealed that leaching had caused a detectable increase in the concentration of certain constituents in the subgrade below the alternative materials. This was noted in Denmark and France below MSWI bottom ash and in the UK below demolition rubble. The increases were limited to a few constituents in each case, and were recorded in both clay and sand subgrade. Results for the Test site are shown on Table 2. Leaching tests and groundwater sampling indicated that the alternative materials did not appear to be having any significant effect on groundwater quality.

Table 2 Leaching of metals into subgrade at La Test site

Depth (cm)	Material	pH	Conductivity (µS/cm)	SO42- (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Reference								
20 – 95	Sand	7.1 – 7.7	28 – 151	4 – 40	0.01 – 0.06	2.5 – 8.2	4.4 – 6.8	2.7 – 7.8
Trench 1								
12 – 32	MSWI ba	9.1	528	713	2	170	1010	2260
32 – 37	Sand	8.6	256	94	0.1	6.1	55	122
37 – 42	Sand	7.1	337	256	0.1	4.4	8.7	8.8
42 – 52	Sand	7.2	190	23	0.04	5.7	7.4	5.5
Trench 2								
35 – 85	MSWI ba	9.0	286	259	4.3	215	1341	4120
85 – 90	Sand	8.9	83	16	0.05	3.1	13	21
90 – 95	Sand	8.9	69	15	0.02	2.7	6.7	9.7
95 – 105	Sand	9.0	103	35	0.1	3.9	29	48

MSWI ba: Municipal Solid Waste Incinerator bottom ash

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MITIGATION MEASURES

Mitigation methods to counter possible adverse environmental effects of the use of alternative materials were considered. These may be either source-based or pathway-based, it being generally impracticable to move the receptors. Source-based methods include ageing of materials such as steel slag and MSWI ash. This allows harmful constituents to hydrate and/or carbonate, avoiding expansion reactions after the material is placed, and the pH of the materials to drop from often highly alkaline values to near neutral.

Pathway-based methods include covering the road surface with a layer of dense, impermeable asphalt or placing low permeability materials on the slopes above the alternative material. The aim is to reduce the contact between water and the alternative materials, and hence reduce the leaching of harmful constituents. These measures should be combined with an effective drainage system.

A further way to reduce contact between percolating water and the alternative material is to stabilize it using bitumen or cement as a binder. This may enable the material to be used in a higher value application such as road base, for which the unbound material may not be suitable.

FURTHER RESEARCH

Two main areas where further research was needed were identified; performance tests for mechanical behavior and measurement of the movement of water through road constructions. In addition, there may also be a need to develop a leaching test suited for slow water movement conditions.

The results from several countries show that alternative materials appear to give better performance in-situ than would be expected from the results of standard laboratory tests. Investigation of alternative materials in tests such as the Los Angeles and Micro-Deval show that their behavior is significantly different from that of natural aggregates. The usefulness of such tests as indicators of in-situ performance must therefore be questioned. Priority should be given to performance-related tests such as cyclic-load triaxial and gyratory compaction. Research is required to develop these tests and relate them to in-situ measures of performance such as the FWD test. The related EC research project COURAGE, dealing with the mechanical behavior of unbound granular materials, came to a similar conclusion.

It became apparent during the project that there were very few reliable data on the movement of water into, through and out of road pavements. As a consequence, the fluxes of contaminants are not known and conservative leaching tests and models are used to estimate environmental impact. The new model developed during ALT-MAT will improve this considerably, but it is still based on a number of fairly conservative assumptions on water movement into and out of road construction. Measurement of the actual quantities of water and contaminants is therefore required to calibrate the model and to enable the development of more accurate models in the future. Water movement in roads also affects the mechanical behavior of the road materials. This area was agreed as a priority for further research by the EC projects POLMIT and COURAGE. (POLMIT dealt with pollution from roads and mitigation measures and, like ALT-MAT and COURAGE was a collaborative research project carried out under the EC's 4th Framework Programme). A programme of laboratory and field tests to evaluate water movement in roads is proposed, leading to the development of a hydro geological model which can be used as a predictive tool for the environmental impact of alternative materials in road construction

There may also be a need to develop a leaching test, which is applicable to granular materials under unsaturated conditions with no or extremely slow flow of water (contaminants transported mainly by diffusion). The development of such a test should also address the need to avoid opening new surfaces of minerals by size reduction of larger aggregates.

CONCLUSION

The results of the ALT-MAT project are very positive and provide support for the use of alternative materials in road construction. The case studies show that the materials perform as well as natural aggregates, and often better than suggested by standard laboratory tests. Methods for testing

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the mechanical and hydrodynamic properties of alternative materials and their leaching behavior are available, and a model for assessing the environmental impact on groundwater quality on a site-specific basis has been developed. It is important that highway authorities and environmental regulatory authorities are made aware of this toolkit of methods and apply them in a national context. The results of the project will be disseminated by seminars in each of the participating countries and by publication of the final report. In addition, the final report will be posted on the ALT- MAT web site at www.trl.co.uk once it has been approved by the EC.

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