THE EMPLOYMENT OF NOT TRADITIONAL MATERIALS IN ROAD INFRASTRUCTURES “THE RESEARCH STATE”

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Summary
The paper gives an overview of the research projects in Europe on the use of alternative materials in road construction. Several research programs have been completed recently (ALT-MAT, SAMARIS, POLMIT, etc.) with very positive results in order to give support for the use of not traditional materials in road infrastructures.
All research programs highlight the difference between the mechanical and enviromental behaviour of many alternative materials and natural aggregate. Therefore the predicted behaviour, deduced from usual laboratory tests, can be different in positive or negative sense. This is not acceptable for a reliable use of "not traditional" materials and it represents the major problem for extensive use in road infrastructures.
The test methods included the mechanical characteristics, leaching and hydrodynamic properties.
Many case studies, reported in literature, show that they give good structural performance and a controlled impact on the pollution of groundwater.

1. Introduction
A large quantities of natural aggregates non-renewable are being consumed to provide transport infrastructure construction and maintenance. The UK total annual production of aggregates had reached, in 1990, 300 millions tonnes and it has become to a lower level of 220 million tonnes in 1997. The continuous use of these resources contributes environmental degradation and energy consumption and, hence, their use for an indefinite period is impossible.
In Europe, in the last decade, there is an increasing interest for the use of the not traditional materials in road applications. The benefits are the reduction of the amount of traditional aggregates regards conservation of natural resources, the reduction of landfill volumes and the riuse of waste materials.
Some European countries have used economic and fiscal tools, such as taxes on landfill and defiscalization on natural aggregates, to encourage the use of alternative materials. Despite these, the extensive use of these materials in road construction is still limited. This is due at:

1) the perception of such materials as a types of "rubbish" and hence very poors;
2) economic reasons such as transport costs;
3) reliability concerns about the mechanical and environmental performance of the materials.

Many questions, with no satisfactory answers, are connected to the assessment of their actual engineering performances and to their effects on the environment.
Several scientific results was obtained in the last years in the understanding of alternative materials behaviour but must still be used to develop a construction methodologies and standard specifications.
Particular interest has the European cooperative research programs ALTMAT, POLMIT and SAMARIS:

- **ALT-MAT** “Alternative materials in road construction”. The main objective of ALT-MAT are to develop methods to assess the suitability of not traditional unbound materials for road application (sub-base, subgrade and embankment). The project, completed in the 1999, was carried out under the “Fourth RTD Framework Programme” of the European Commission, involving seven european countries coordinated by the TRL (UK), with a wide range of climatic conditions, alternative and natural materials and methods of road construction.
- **SAMARIS** “Sustainable and advanced materials for road infrastructure”. SAMARIS is a research project from the Growth program of the 5th Framework Programme, financed by the EU Commission and others public partners. The primary aim of the project is to

encourage a greater use of recycled components in pavement materials. The second main objective is to prepare for the harmonisation of European approaches of material specification within the next generation of CEN standards. This implies moving from a recipe approach, which puts much emphasis on the intrinsic characteristics of the constituents, to a performance-based approach in-situ.

- **POLMIT** “Pollution of Groundwater and Soil by Road and Traffic Sources: Dispersal Mechanism, Pathways and Mitigation Measures”: The project aims at providing an understanding for the absolute and relative importance of potential sources of pollution in and around roads, including investigations of the spreading of pollutants in soil and groundwater. The project is carried out under EU - DG XII “Transport Programme” with the "Danish Road Institute" and others six european organizations.

The european cooperative reseach program COST 351 “Water Movement in Road Pavements and Embankments”, started in 2003, aims to increase the knowledge required for improving the highway performance and minimising the leaching of contaminants from roads and traffic.
In the paper are summarized the main results from above research projects

2. Not traditional materials for road infrastructures.

The Figure 1 show the possible applications of not traditional materials.: bituminous layer (surface course and road base), granular layer (sub-base and sub-grade), shoulders and landscaping, enbankments and flowable fill.

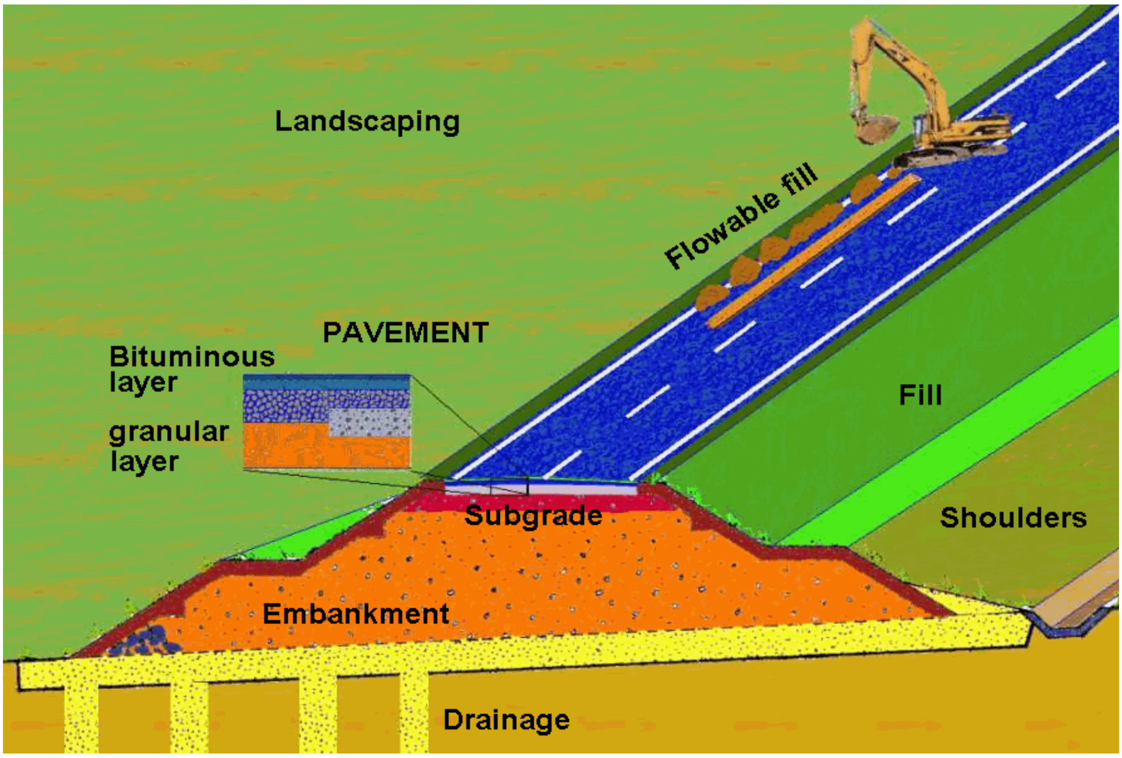

Figure 1 Possible road applications of not traditional materials

The not traditional materials used varied from country to country and included crushed concrete, reclaimed asphalt pavement, bottom ash, fly ash, scrap tires, foundry sand, steel slag, blastfurnace slag, recycling glass and municipal solid waste incinerator (MSWI).
The main areas where it is possible to introduce this kind of material are very different. Usually in asphalt concrete layers they represent a small part of the mix while they can completely replace the natural aggregate in the subgrades, in the embankments and fills. Some applications include the asphalt cement modifier, additional cementitious component in road base and soils stabilization. The Figure 2 shows main applications and use of alternative materials.

APPLICATION – USE	MATERIAL
Asphalt Concrete – Aggregate (Hot Mix Asphalt)	Blast Furnace Slag, Coal Bottom Ash, Coal Boiler Slag, Foundry San Mineral Processing Wastes Municipal Solid Waste Combustor Ash, Nonferrous Slags, Reclaimed Asphalt Pavement, Roofing Shingle Scrap, Scrap Tires, Steel Slag, Waste Glass
Asphalt Concrete – Aggregate (Cold Mix Asphalt)	Coal Bottom Ash, Reclaimed Asphalt Pavement
Asphalt Concrete – Aggregate (Seal Coat or Surface Treatment)	Blast Furnace Slag, Coal Boiler Slag, Steel Slag
Asphalt Concrete – Mineral Filler	Baghouse Dust, Sludge Ash, Cement Kiln Dust, Lime Kiln Dust, Coal Fly Ash
Asphalt Concrete – Asphalt Cement Modifier	Roofing Shingle Scrap, Scrap Tires
Portland Cement Concrete – Aggregate	Reclaimed Concrete
Portland Cement Concrete – Supplementary Cementitious Materials	Coal Fly Ash, Blast Furnace Slag
Granular Base	Blast Furnace Slag, Coal Boiler Slag, Mineral Processing Wastes, Municipal Solid Waste Combustor Ash, Nonferrous Slags, Reclaimed Asphalt Pavement, Reclaimed Concrete, Steel Slag, Waste Glass
Embankment or Fill	Coal Fly Ash, Mineral Processing Wastes, Nonferrous Slags, Reclaimed Asphalt Pavement, Reclaimed Concrete, Scrap Tires
Stabilized Base – Aggregate	Coal Bottom Ash, Coal Boiler Slag
Stabilized Base – Cementitious Materials (Pozzolan, Pozzolan Activator, or Self-Cementing Material)	Coal Fly Ash, Cement Kiln Dust, Lime Kiln Dust, Sulfate Wastes
Flowable Fill – Aggregate	Coal Fly Ash, Foundry Sand, Quarry Fines
Flowable Fill – Cementitious Material (Pozzolan, Pozzolan Activator, or Self-Cementing Material)	Coal Fly Ash, Cement Kiln Dust, Lime Kiln Dust

Figure 2 Main use of alternative materials

Figure 3 Some alternative materials: tires, rubber, concrete, MSWI, glass, C6D

Not conventional material could be used for road construction if the characteristics and the performance of those materials is similar to that of virgin construction and these materials could be obtained without causing any impact on the environment and unjustified extra costs.
In SAMARIS project alternative reusable materials have been distinguished into two categories: by-products and materials at the end of serviceability life. The first is obtained from producing another material while the second type is the unwanted material at the end of the consumption cycle.

These materials are originating from six different sources/ products:

1. Mining and quarry
2. Metallurgical
3. Industrial
4. Municipal
5. Agricultural and forestry
6. Demolished materials

The choice of alternative materials in different countries has primarily been based on occurrence, availability and sustability.

Laboratory tests are conducted to assess the performance of road constructed with alternative materials in many countries. Usually the test include: analysis in situ and monitoring of sections of road which had been constructed using not traditional materials; lysimeter tests to simulate a road construction unpaved; climate chamber tests to verify the effects of freezing-thawing and wetting-drying cycles on the long time performance; mechanical, leaching and hydrodynamic tests in the laboratory. Generally, natural materials are also tested in order to have reference parameters.

2. Mechanical Tests

To verify if alternative materials might behave in a different manner from natural aggregates in standard laboratory tests, in the ALTMAT research program carried out several inter-laboratory specific tests.

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 behaviour 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 3.

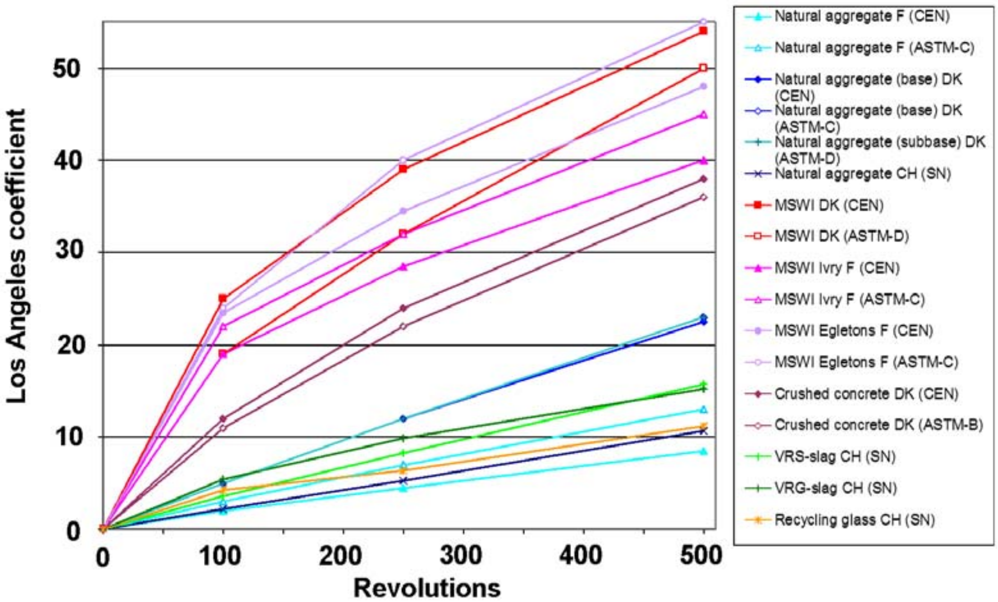

Figure 4 Los Angeles abrasion tests for alternative materials carried out under ALTMAT research program

This confirm that alternative materials behave in a different way from natural aggregates. The natural materials have a linear behaviour, whereas the response of the alternative materials is non-linear. This is more evident for the MSWI bottom ash, with much greater breakdown of material at the beginning of the test. Crushed concrete occupies an intermediate position. A similar pattern was found in the Micro-Deval tests.

The not traditional materials generally give much higher Los Angeles coefficients than natural aggregates, indicating that they are more weak and fragile. However, the mechanical tests in situ are often better than obtained from laboratory analysis. Design therefore should be based on

performance tests such as cyclic load triaxial or gyratory compaction. Experimental work is needed to compare traditional laboratoy tests and in situ performance measurements.
Existing CEN mechanical tests for granular materials were reviewed in ALTMAT research program for their suitability for not traditional 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); vibrocompression with controlled parameters (prEN 13286.3); vibrating hammer (prEN 13286.4); vibrating table (prEN 13286.5).
Not traditional materials tests that use vibration are recommended rather than impact tests. A test method for the self-binding attitude of alternative materials is needed, as is an improved method to describe the material composition.

3. Leaching Tests

The leaching behaviour of not traditional materials was analized by a combination of laboratory tests, lysimeter tests and climate chamber tests. European standardisation 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 ALTMAT research project, and the following tests are recommended for characterisation of alternative materials:

- Characterisation 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 solubility of many species is pH dependent. Thus, the pH dependency of the leaching behaviour should also be investigated, using a pH-static leaching test. If the pH of the material or solution may change its leaching behaviour should be determined at a range of pH values.
The purpose of lysimeter or others tests is to simulate the effect of climate on a road infrastructures with or without a pavement. Lysimeters are large boxes filled with material and left open to the atmosphere. The drainage water is collected and analysed.
Figure 2 shows the results of ALTMAT laboratory leaching tests, plotted as the cumulative amount leached (mg/kg) against the Liquid/Solid (L/S) ratio.

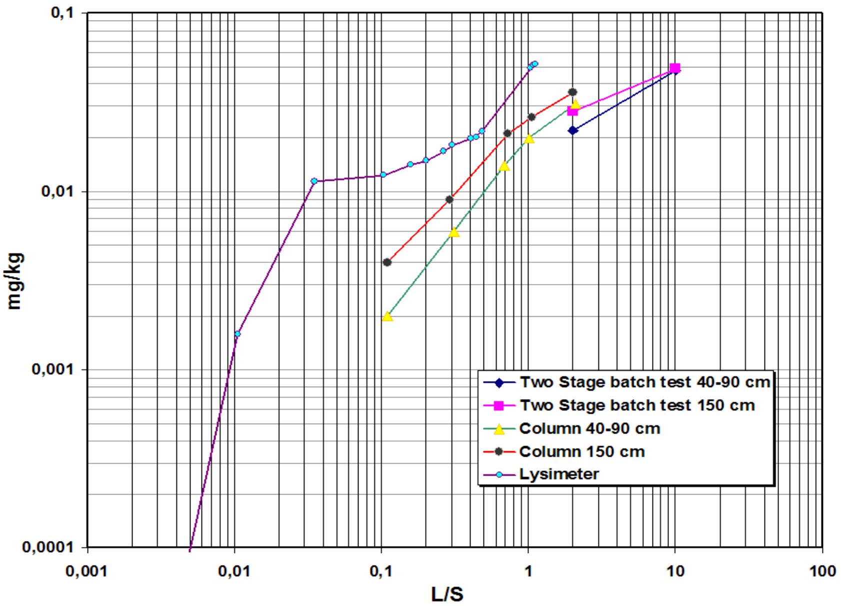

Figure 5 Amount leached (mg/kg) versus Liquid/Solid (L/S) ratio (souce ALTMAT)

When the materials were covered by an impermeable layer of asphalt, more ten times longer is necessary to the same 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 important difference between field behaviour and laboratory leaching tests is the effect of atmospheric exposure. Laboratory tests are carried out in a fully saturated situation, whereas in a road embankment and superstrucrures conditions will be unsaturated for most of the time. Several reactions can thus occur in situ, which affect the leachate characteristics (oxidation of sulfides, hydration of minerals, carbonation of cement). This can modify the pH, and hence leaching tests should be conducted with similar pH in the field, using pH-static tests.
A description of the source of the contamination from the application is needed as an input to the groundwater transport/attenuation silulation. In 1999 Hjelmar has proposed a useful model to predict the impact of leaching from materials in road construction.
In the model leaching of several components may be expressed by a simple decay function:

$$C = C_0 e^{-\left(\frac{L}{S}\right)k}$$

where C is the concentration of the contaminant in the leachate as a function of L/S (mg/l), C0 is the initial peak concentration of the contaminant in the leachate (mg/l), L/S is the liquid to solid ratio corresponding to the concentration C (l/kg) and where kis a kinetic constant describing the rate of decrease of the concentration as a function of L/S for a given material and a given component (kg/l). kvalues may be estimated from column, lysimeter or serial batch leaching data.
By integrating the above expression, the amount of contaminant, E (in mg/kg), released over the period of time it takes for L/S to increase from 0 l/kg to the value corresponding to C, can be calculated:

$$E = \frac{C_0}{k}\left(1 - e^{-\left(\frac{L}{S}\right)k}\right)$$

The relationship between time and L/S for a percolation flow situation can be derived from the specific situations:
t = (L/S) * d * H/I
where t is the time since the application started producing leachate, L is the total volume of leachate or percolate produced at time t, S is the total dry mass of material in the application or layer in question, d is the average dry bulk density of the material in the application, H is the average height of the application or the layer in question and I is the net rate of infiltration of precipitation percolating through the application.
The flux of contaminants from the base of a granular material application percolated by infiltrated precipitation is then described as a function of time by substituting the L/S with time in the above expression for C and multiplying that with the estimated rate of flow of water through the material.
The characterisation 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 characterisation tests may be required.
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 specific situation.

5. Mitigation measures

Mitigation methods 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.
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 stabilise it using bitumen or cement as a binder. This may enable the material to be used in a higher value application such as roadbase, for which the unbound material may not be suitable.

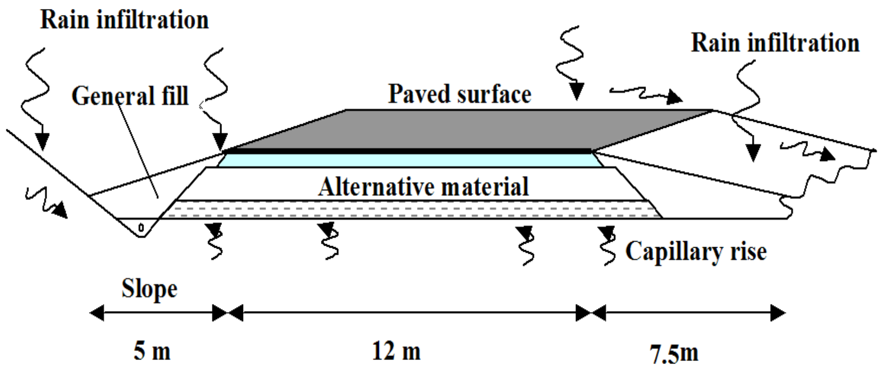

Figure 6 Water movement into a road infrastructures (source ALTMAT)

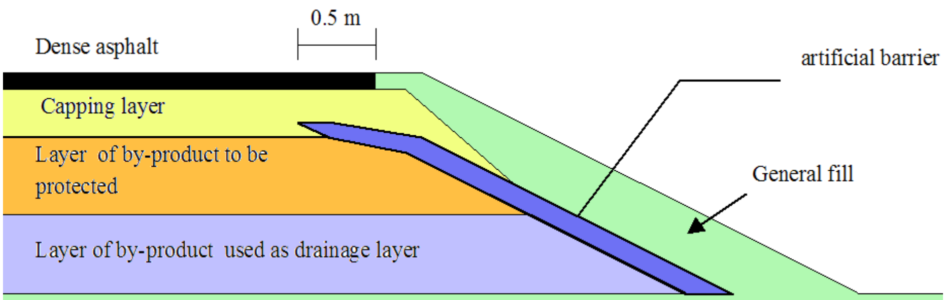

Figure 7 Mitigation by impermeable layers.

Measure	Advantages	Disadvantages	Application situations
Basic covering	Cheap, some maintenance with asphalt layer	Covering must remain efficient	Basic alternative to the materials with low leaching risks
Dense asphalt and impermeable layer in slopes	Relatively economic	Measure must remain efficient	To demanding circumstances
Effective drainage system	Must be combined with other methods, economic	Some extra maintenance is needed	Must be combined with other methods
Treatment: stabilisation, ageing, cooling etc.	Depends on treatment, can be very effective	Material-specific, can be expensive, not much experience	Can be combined with other methods
Impermeable bottom layer	Quite safe measure	The most expensive, separate drainage and water treatment systems needed, maintenance of drainage systems	To very demanding circumstances, important ground water areas etc.

Table 1 Mitigation measures for road construction

6 Mechanical performance

The monitoring of existing roads was carried out in ALTMAT project in Sweden, Denmark, the United Kingdom and France. The materials, investigated under different climatic conditions, include demolition rubble, crushed concrete, MSWI bottom ash, air-cooled blastfurnace slag and natural reference materials. These materials were employed in unbound granular sub-base and subbase, as shows in Table 2. Falling Weight Deflectometer (FWD) and trial pits and trenches were carried out for a visual inspections and mechanical evaluation of materials stiffness characteristics. Moreover, in-situ standard tests such as density and plate bearing were carried out and samples taken for laboratory analysis. Samples of groundwater were taken for analysis. The road sections with not traditional materials showed that it gave as good and sometimes better support to the pavement than natural reference materials. This is shows for E-moduli in Table 2. The results in situ was often better than would have been predicted from standard laboratory tests such as CBR or Los Angeles abrasion value.

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	Crushed concrete	Sand	8	120	540
	Vejle	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

Table 2 Case studies

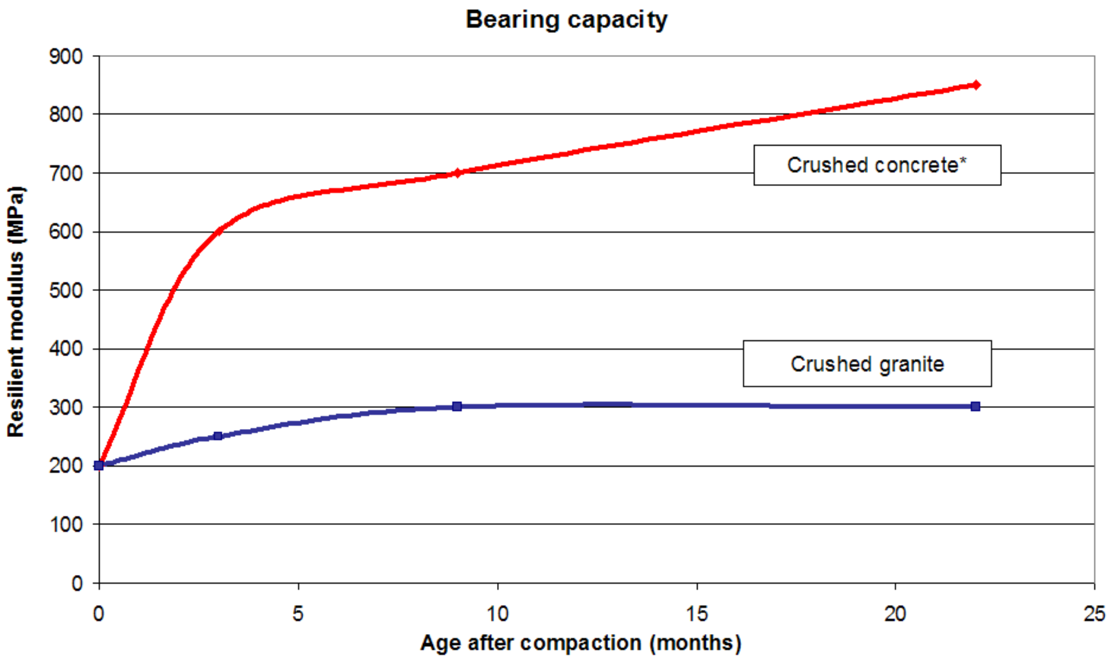

Figure 8 Resilient modulus from FWD versus time for crushed concrete sub-base (source ALTMAT)

Figure 9 Ffield density and Falling Weight Deflectometer Measurement

Conclusions

The results from several research projects in Europe on the use of alternative materials in road construction have been completed recently with very positive results in order to give support for the use of not traditional materials in road infrastructures. However, all research programs highlight the difference between the mechanical and enviromental behaviour of many alternative materials and natural aggregate. Therefore the predicted behaviour, deduced from usual laboratory tests, can be different in positive or negative sense. This is not acceptable for a reliable use of "not traditional" materials and it represents the major problem for extensive use in road infrastructures.

Therefore, two main areas where further research was needed were identified; performance tests for mechanical behaviour 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. For mechanical characteristics priority should be given to performance-related tests.

Some European countries have used economic and fiscal tools, such as taxes on landfill and defiscalization on natural aggregates, to encourage the use of alternative materials. Despite these, the extensive use of these materials in road construction is still limited. This is due at the perception of such materials as a types of "rubbish" and hence very poors, at economic reasons such as transport costs and at reliability concerns about the mechanical and environmental performance of the materials.

It is important that highway agency and environmental regulatory authorities are made aware of this toolkit of methods and apply them in a national context.

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