Proposal of Catalogue of Pavements with Construction and Demolition Waste for Low Volume Traffic Roads

Ana Rita Monteiro Rocha Martins

Instituto Superior Técnico, Lisbon, Portugal

September 2015

Abstract

Recycling turns residues, often considered worthless, into resources, with environmental, economical and social advantages. The use of construction and demolition waste (CDW) in road pavement construction and rehabilitation is one such example. This dissertation lies in the context of the SUPREMA project, namely the analysis of the behavior of pavement structures where CDW were used. In particular, the use of some of these aggregates in unbound layers of pavements is proposed. The field of application of these materials in pavement strutures was determined with the LNEC Specifications, the Guide for the use of Construction and Demolition Waste in Municipal and Rural Roads and Trenches, and the Spanish Guide, as frameworks. The structures were analysed for a certain design and traffic conditions, for a design period of 10 years, under Shell's and the mechanistic-empirical (MEPDG) approaches. The MEPDG uses AASHTOWare® pavement design software (DARWin-ME) which, based on material, traffic and climate properties, predicts the pavement behavior over time. This time evolution was studied in terms of roughness (IRI), total deformation and fatigue cracking. This dissertation compiles the viable solutions for CDW usage in base and sub-base layers into different catalogs, aiming to aid the designer in early conception stages, but without dismissing the need for actual in-situ validation of the chosen structure, via the design method most suitable to the project.

Keywords: road, pavements, catalogue, design, CDW, MEPDG.

1 Introduction

Recycling converts waste into resources (Sirigiripet, 2007). It has become a commonplace practice, with evident and ubiquitous benefits, namely from the environmental, economic and social standpoints.

From the point of view of the Environment, recycling has the potential to: (1) increase the life expectancy of natural resources; (2) reduce the amount of residues, waste and the environmental stress around construction sites; (3) improve the sustainable development of natural resources, by slowing down their rate of exhaustion (Sirigiripet, 2007).

Economically speaking, the advantages encompass (1) the rise of Recycling industry, thereby creating employment; (2) reducing the dependence on raw materials and thus smoothing the competition over price; (3) reducing the usage of landfills, saving both in transportation and storage of materials (Spies, 2009), by the increasing trend of in-situ recycling. It is indeed a viable alternative to the current practices, with enourmous potential for application as unbound materials for capping, base and sub-base of pavements (Freire, et al., 2013).

At the social level, the advantages include better usage of public areas and an overall improvement in Public Health (Spies, 2009).

This thesis aims at the characterization and validation of the performance of Construction and Demolition Waste (CDW) materials in unbound layers of road pavements, thus contributing for the consolidation of the three abovementioned facets of Sustainable Development.

Guidelines and project catalogues were obtained for the development of pavements with CDW layers, for a project lifetime of 10 years, using Shell's method. In addition, the pavement structures were analysed using the Mechanistic-Empirical Pavement Design Guide (MEPDG), using the DAWin-ME software.

The MEPDG allows for a precise prediction of the pavement's evolution over time, thereby enabling the determination of the suitability and performance of the pavement project (Rabab'ah, et al., 2007) at design-time. Furthermore, it helps the designer in the prediction of poor pavement performance, which in the long run translates into poor user experience and structural failure, which in turn reduces the economic, human, and environmental footprints.

2 SUPREMA project

The pavement structures analysed were described using the material properties used in the SUPREMA project.

This project, "SUPREMA – Aplicação Sustentável de Resíduos de Construção e Demolição (CDW) em Infra-estruturas Rodoviárias", funded by the national R&D program (PTDC/ECM/100931/2008) da Fundação para a Ciência e Tecnologia (FCT) do Ministério da Educação e Ciência, had as main goal studying the sustainable application of CDW in road infrastructures, in particular in the unbound layers (Freire, et al., 2013).

For this, three recycled aggregates with little-know properties and performance were selected (Simões, 2013):

- CAM (Crushed Mixed Asphalt) – recycled aggregate made of asphaltic waste from the crushing of mixed asphalt, recovered by milling;
- MCC (Mixed Crushed Concrete) – recycled aggregate made of mixed waste from crushed concrete and masonry;
- COMP (70% CAVGS and 30% milled mixed asphalt) – recycled aggregate made of asphaltic waste from mixed asphalt, recovered by milling, and then mixed with CAVGS limestone.

CDW have been characterized by their properties (Table 2.1).

Table 2.1 – Composition of CDW used in the SUPREMA project.

Material	R_c	R_u	R_g	R_c+R_u+R_g	R_b	R_a	FL	X
CAM	19	10	0	29	1,8	69,1	0,1	0
MCC	67,55	16,5	0,25	84,3	13,15	1,85	0,6	0,1
COMP	0,03	75,1	0	75,13	0	24,87	0	0

Legend: R_a (%) – Asphaltic material; R_b (%)– Clay-based masonry materials (bricks, roof tiles, etc.), Limestone silicate-based masonry material and aerated concrete; R_c (%) – Concrete, concrete products and mortar; R_g (%) – glass; R_u (%) – Unbound aggregates, rock, hydraulic bound aggregates; X (%) –

wood; ferrous and nonferrous metals; rubber; plaster; clay and soil particles; FL (cm3/kg) – Volume of floating material.

These materials were also classified by their geometrical, chemical and mechanical properties, as shown in Table 2.2.

Table 2.2 – Material properties studied in project SUPREMA.

Property	Standard	CAM	MCC	COMP
Maximum dimensions (mm)	NP EN 933-1	31,5	40	31,5
Fines content (sieve # 0,063 mm, %)	NP EN 933-1	3	3,5	5,7
Oversize	NP EN 933-1+A1	OC80	OC90	OC90
Fines content (max./mín.)	NP EN 933-1+A1	UF3/LF2	UF5/LF2	UF7/LF4
Granulometric class	NP EN 933-1+A1	GA	GC	GP
Sand equivalent (%)	NP EN 933-8	84	92	47
Methyline blue, MB (g/kg)	NP EN 933-9	0,7	2,2	3,7
LA abrasion	NP EN 1097-2	25	38	27
Wear resistance, MDE (%)	NP EN 1097-1	18	36	18
Water-soluble sulfates content	NP EN 1744-1	0,01	0,08	0,01

3 Input data

3.1 Materials

Following the data collection from project SUPREMA, a systematic classification based on the following specifications was conducted and summarized in Table 3.1: (a) LNEC E 473 specification (LNEC, 2009a) and LNEC E 474 specification (LNEC, 2009b); (b) Proposal for amendment of the the LNEC guide for the use of CDW in municipal and rural roads and trenches (Rodrigues, 2013); (c) GEAR guide (GERD, 2011).

Table 3.1 – Classification of the recycled aggregates as unbound layers.

Methodology		CAM		MCC		COMP	
		Class	Category	Class	Category	Class	Category
LNEC	E 473	-	AGER1/AGER2	C*	AGER1*	C	AGER1
	E 474	MB	MAT1/MAT2	C	MAT1/MAT2	C	MAT1/MAT2
Porposal for amendment		MB	all	C/C1*	all	C/C1	all
GEAR		-	-	ARMh	CL4/CL3	ARMa	all

* Does not fulfill all criteria, but is close to limiting values.

These methodologies account for the possible applications of CDW, as described in Table 3.2.

Therefore, MCC and COMP materials may be applied in base and sub-base layers. CAM shows weaker properties and is considered valid only for sub-base layers under the LNEC method. It will not be considered in this thesis.

3.2 Subgrade soils

For this dissertation, 3 types of soils were chosen: S2, S3 and S4, consisting mainly of clays, claysands and silt (S2), silty sands and poorly graduated sands (S3) and well graduated sands, claygravel, silty gravel and poorly graduated gravel (S4).

Table 3.2 – Recommended application for the recycled aggregates studied.

Methodology		CAM	MCC	COMP
LNEC	E 473	-	**sub-base (AADTT < 50)***	sub-base (AADTT < 50)
	E 474	-	Capping	Capping
Porposal for amendment		sub-base	sub-base, **base***, **wear***[1]	sub-base, base, wear[1]
GEAR[2]			Sub-base, base: **T3***, **T4*** e <T4	Sub-base, base: T3, T4 e <T4

[1] Uncoated traffic wear layers; [2] Spanish classes T3 and T4 correspond to the portuguese classes T5/T6 e T7, respectively; * Does not fulfill all criteria, but is close to limiting values.

Two types of foundation, matching the conditions in Portugal, were used: F2 and F3. The deformation modulus considered were 60 MPa and 100 MPa for F2 and F3, respectively, as recommended by the MACOPAV.

Each type of soil was then classified according to the american AASHTO system, for subsequente analysis of pavement structures using the DARWin-ME software. This association was based on the properties of the chosen soils: A-2-4 for S3 class and A-1-a/b for S4 class soils. Given the evaluation of MCC and COMP, these materials are suited for S4 soils, allowing for their usage as capping layers.

The load-bearing capacity between layers made of recycled materials was derived from actual in-situ measurements (April 2013 campaign of the SUPREMA project):

- CAM and MCC: a relation of 1.7 was considered between support layers and layers made of these materials, both for sub-base and base;
- CAVGS, the empirical relation in Claessen et al. (1977) was adopted;
- COMP, a relation of 2.0 was chosen for 20 cm layers and 1.8 for 15 cm layers.

This campaign was chosen because (1) it took place in wintertime, when the unbound layers and foundation of the pavement exhibit the lowest load-bearing capacity, and (2) it was the one with the greatest gap between construction and survey time, allowing for a greater stabilization of the layers and a behavior closer to steady-state conditions.

3.3 Truck traffic

Three types of traffic were considered, to which different road and traffic distribution classes were associated:

- T7a: AADTT < 25 - local access roads, forest tracks and country lanes (TTC 14)
- T7b: AADTT < 50 - local traffic hubs, local access roads and country lanes (TTC 14)
- T6: AADTT = [50; 150[- local traffic hubs (TTC 12 e TTC 14)

Based on the spanish standard, it was decided to split the T7 traffic class and consider a traffic growth rate of 2%, since the guideline in Portugal forces designers to carry out a specific study, for roads with heavy traffic lower than 50 vehicles/day. The agressive factor, in turn, was considered the same for T6 and T7 (α=2). The other parameters were chosen according to the common practices in Portugal.

These traffic distribution classes were chosen for their closeness to the cases of interest:

- TTC 14 – predominance of single-unit trucks; few to zero multi-trailer trucks; no buses;
- TTC 12 – mixed heavy traffic, with predominance towards single-unit trucks and a few trailer trucks; few to zero multi-trailer trucks; few buses.

These groups stand out as they express most accurately the situations of interest in Portugal, namely the F1 and H5 classes (american classes 5 and 9, respectively).

3.4 Climate conditions

Climate data from the cities of Beja, Lisboa, Coimbra and Porto were chosen as representative of the different weather conditions in Portugal.

For the Bisar software, temperature values were obtained from the PAVIFLEX software (Baptista, 1999), in particular for traffic classes T6 and T7 and foundation types F2 and F3. For class T7 the values of T6 were used.

For the DARWin-ME software, the source of temperature data was an ICM (Integrated Climatic Model) file produced by the Instituto Superior de Engenharia de Coimbra, which, together with the University of Maryland, conducted a thorough analysis.

4 Pavement structures

The behaviour evaluation of the pavement structures was based on the computation of their limit failure states, defined in terms of the accumulated number of equivalente axle loads. These states consisted of fatigue cracking and permanent deformation. Their safety analysis was made by comparing the applied and allowable extensions.

To evaluate the the applied extensions, Shell's approach was used, with an standard axle load of 80 kN.

The layer thickness in the chosen structures was obtained in MACOPAV and ORDEN FOM/3460/2003, the portuguese and spanish guides for flexible pavement structures, respectively. For the latter, it was necessary to adjust the inputs. In particular, the foundation class chosen was E1 (E ≥ 60 MPa), the closest to the portuguese classes F3 and F2 (Correia, et al., 1997).

The traffic classes chosen were the spanish T4.2 and T4.1, corresponding to a maximum AADTT of 25 and 50 trucks/day, respectively.

4.1 Catalogs of pavements

These catalogs (Tables 4.1 and 4.2) exhibit the solutions found for low-traffic (classes T7 and T6) road pavements for foundation classes F2 and F3.

The proposed structures correspond to the most likely to occur in Portugal and may be used as a guideline at the conception stage of a project, but does not replace the designer's own validation by the proper dimensioning methods.

The usage of CDW shall be confined to two layers per pavement: whenever it's used in the capping layer, it may only be used in the sub-base layer.

The design lifespan of 10 years was chosen because the material properties are still not fully understood and traffic patterns are intrinsically difficult to forecast for long periods of time.

These tables do not take into account the combinations of materials, as it is unrealistic for a project to procure sufficient CDW materials of different types for a full road pavement.

Some structures use uncoated layers; however, these solutions shall not be applied in: (a) locations where high tangential stresses are expected (parking lots, etc.) and (b) infrastructures with slopes higher than 4 % to ensure vehicle safety. The solution proposed for the latter case is the usage of a double surface coating. For slopes higher than 10%, an asphalt concrete wear layer with 4 cm of AC 14 surf 35/50 is recommended.

Table 4.1 – Catalog A: Structures with granular layer made of MCC and CAVGS and design lifespan of 10 years.

Traffic / Foundation	T7a (uncoated layer)	T7a	T7b	T6
F2	H	A 1: AC 14 surf (5) AC 20 bin (5) BBM (20) BBM (20) 2: AC 14 surf (5) ABGE (20) BBM (20)	B 1: AC 14 surf (5) AC 20 bin (7) BBM (20) BBM (20) 2: AC 14 surf (5) AC 20 bin (7) ABGE (20) BBM (20)	C
F3	G 1: double surface coating BBM (15) BBM (15) 2: ABGE (15) BBM (15)	D 1: AC 14 surf (5) BBM (15) BBM (15) 2: AC 14 surf (5) ABGE (15) BBM (15)	E 1: AC 14 surf (5) BBM (20) BBM (20) 2: AC 14 surf (5) ABGE (15) BBM (15)	F 1: AC 14 surf (5) AC 20 bin (7) BBM (20) BBM (20) 2: AC 14 surf (5) AC 20 bin (5) ABGE (20) BBM (20)

(layer thickness in cm)

Table 4.2 – Catalog A: Structures with granular layer made of Compound mixtures and CAVGS and design lifespan of 10 years.

Traffic / Foundation	T7a (uncoated layer)	T7a	T7b	T6
F2	H ABGE (20) COMP (20)	A AC 14 surf (5) COMP (20) COMP (20) AC 14 surf (5) ABGE (20) COMP (20)	B AC 14 surf (5) AC 20 bin (5) COMP (20) COMP (20) AC 14 surf (5) AC 20 bin (5) ABGE (20) COMP (20)	C
F3	G double surface coating BBM (15) BBM (15) ABGE (15) COMP (15)	D AC 14 surf (5) COMP (15) COMP (15) AC 14 surf (5) ABGE (15) COMP (15)	E AC 14 surf (5) COMP (15) COMP (15) AC 14 surf (5) ABGE (15) COMP (15)	F AC 14 surf (5) COMP (20) COMP (20) AC 14 surf (5) ABGE (20) COMP (20)

(layer thickness in cm)

5 Mechanistic-empirical Approach (MEPDG)

5.1 DARWin-ME Software

The MEPDG aims at evaluating the pavement performance for a given project lifespan.

It is a mechanistic method, in that it uses models based on the stress-strain behaviour of the pavements, based on the responses of actual pavements to loads (Dzotepe & Ksaibati, 2010) but also an empirical method, in that the results yielded by software can be calibrated using observed values of parameters.

The MEPDG uses a user-friendly pavement design software by AASHTOWare®, DARWin-ME. The pavement structure analysis is carried out by inputting the material, traffic and climate parameters. By an iterative trial-and-error approach, estimated deflections can be computed, based on the confidence level chosen (also by the user). (Daniel & Chehab, 2007).

DARWin-ME parameters are divided in three levels, according to their source; level 1 corresponds to actual measurements and level 3 to "best estimates" or default values (AASHTO 2008). In the same project different input levels may be used.

5.2 Agressive factor

In order to replicate the conditions considered by Shell's approach, some were criteria from the MEPDG were employed, namely the aggressive factor.

The DARWin-ME software considers several traffic inputs contributing to the agressive factor, namely the axle load factor (ALF), the number of axles, number of axle types per truck class (NAT), vehicle class distribution (VCD) e truck hourly distribution factor (THDF) e monthly adjustment factor (MAF). Besides the abovementioned input data, the equivalente axle load factors (EALF) must be considered to estimate the equivalent single axle loads (ESAL). In this project, the standard load is of 18-kip (80,068 kN) for single axles.

The equivalent axle loads used were found in the appendix D of the "Guide for Design of Pavement Structures", 1993 (tables D.10 to D.18). A structural number (SN) of 5 and a pavement service index (p_t) of 2.5 were used.

The aggressive factors for the different truck traffic classifications (TTC) lie within the interval [0.6; 1.2]. For classes 12 and 14 they are of of 0.7 and 0.6, respectively, much lower than the reference level from the MACOPAV for a T6 traffic class and axle load of 80 kN (α=2).

Given the discripancies encountered, the values for AADTT (input to the application) were corrected to account for them.

5.3 Climate comparison

Global calibration of the MEPDG software does not function equally well on all regions (US states), which is somewhat expectable, given the variety of climates found in the US, and their effects on pavement performance.

Climate data was collected from the southern states of the US. In particular, the following variables were used: average yearly temperatures (ºC), average yearly precipitation (mm), days with precipitation, freezing index and freeze/thaw cycles. These variables were weighted according to Byram et al. (2011), where also the influence (in %) of each in the performance of the pavement were determined.

The conclusion was that the US state with the weather most similar to Portugal is California, with the averages of all parameters very close to their portuguese conterparts. South Caroline comes next in the ranking, in particular given the large weight of average yearly temperature. These two states shall be studied further during the implementation of the MEPDG in Portugal.

5.4 Pavement analysis

The pavement structures were evaluated according to the IRI criteria: 3 m/km (CETO Cap 15.03), total deformation of 16.5 mm (value recommended for roads with v < 72 km/h AASHTO, 2008) and 35% AC bottom-up fatigue cracking (default value in the DARWin-ME software), for a confidence level of 90%.

The conditions in Portugal were replicated was well as possible. However, a few exceptions deserve mentioning: (a) the wear layer AC 14 surf 35/50, very common in Portugal, is not recognized by the software, the asphalt penetration chosen was then 40-50; (b) the application supports only flexible or rigid pavements, rendering the modelling of asphalt-less structures impossible; a minimal asphalt layer of 2.5 cm was used instead.

The total deformation was the only failure mode for which the project criterion was not fulfilled. 7 out of the 32 pavement structures considered valid under the BISAR software deformed more than the allowable limit with the DARWin-ME software. No relevant relations were established between these structures and the materials, traffic or climate conditions.

The evolution of this failure mode is similar for all pavement structures considered: there are two distinct stages in the deformation behaviour, namely a quick growth until ¼ of the project lifespan and then a smoother growth thereafter. The plots also show a decreasing slope at 5 years time, which, while not particularly important, shows the sensitivity of the software to time changes.

The values obtained for fatigue cracking and IRI are much lower than the perscribed limits for the project lifespan.

The project guide from AASHTO (2008) identifies the functions used to predict pavement performance and compares them, based on a global calibration process, using the LTPP study.The results show that the models used for these calibrations were unable to reproduce real situations. The values for R^2 for global deformation, fatigue cracking and IRI are of 0.577, 0.275 and 0.56, respectively.

6 Conclusions

CDW materials may be deemed viable, as they allow for sufficient structural quality of pavements, and are to be thought of as valid choices in pavement design projects.

Two easy-to-use catalogs were developed for 10 year project lifetimes, and organized by material type, and are valid for low-traffic road pavements (traffic classes T7 and T6) and foundation classes F2 and F3.

Studying recycled CAM materials was, together with BBM and HMA, one of the goals of the SUPREMA project. However, material classification doesn’t fit the model in LNEC specifications, in the sense that these materials don’t fit the requirements for base and sub-base of road pavements.

The pavement structures were analysed with the DARWin-ME software. Only 80% of them, albeit being already validated for the current practice in road design in Portugal, matched the imposed limits. It was also determined that the total deformation of the betominous and granular layers of the pavements were the only cause for failure.

DARWin-ME was designed to account for local weather conditions. Since the bulk of existing results was related to the USA, weather parameters from there and Portugal were compared. It was determined that the US states most similar to Portugal are California and South Carolina.

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