Utilization of recycled materials in unbound granular layers validated by experimental test sections

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ABSTRACT: The utilization of recycled materials has obvious environmental and economic benefits that contribute for a more sustainable construction and rehabilitation of road pavements. Despite the fact that many studies have already focused on the reusing and recycling of materials, further research is always important to achieve a deeper knowledge on these materials and technologies, and to increase the confidence of road owners and construction companies for their use. This is the case of reclaimed asphalt, it is a material with an enormous potential to be used in "unbound granular layers", when it is not possible to incorporate it in new asphalt mixtures. This paper concerns the structural evaluation of the Construction and Demolition Recycled Materials (C&DRM) used in unbound granular layers of bituminous pavements based on experimental test sections. An extensive study was performed in experimental pavements, instrumented during the construction and submitted to loading tests, where recycled materials were used in granular layers of sub-base and base. This is part of the ongoing project SUPREMA – Sustainable Application of Construction and Demolition Recycled Materials (C&DRM) in Road Infrastructures – by the National Laboratory for Civil Engineering (LNEC, Portugal), in cooperation with the Technical University of Lisbon (IST, Portugal) (2010-2013). The aggregates used in the experimental sections were selected from C&DRM (crushed concrete and ceramic mixtures, reclaimed asphalt material – crushed asphalt and milled material), and a natural material (limestone) as the reference material. Four sections were instrumented with strain gauges and load cells, placed in pavement layers and subgrade soil. The paper presents the results from in-situ loading test series performed by the Falling Weight Deflectometer (FWD), for deflections measurements of the instrumented pavements with different C&DRM and a natural material. Analysis of results during load tests has demonstrated an acceptable performance of layers with recycled materials.

KEY WORDS: Road pavements, Recycled materials, Test sections, FWD tests, Bearing capacity

1 INTRODUCTION

In recent years, the reuse and recycling of construction and demolition waste in road construction has increased significantly, resulting in an important contribution for a more economical and sustainable construction and maintenance. This is the case of the application of recycled aggregates from different origins in unbound granular sub-base and base layers of pavements.

Intensive research, based on experimental work, is essential in order to overcome definitively empirical approaches in the design and construction using recycled aggregates for purposes of transportation infrastructures and geotechnical structures. So, experimental investigation involving laboratory tests (e.g. large-scale triaxial tests) and in situ tests (e.g. plate load tests, falling weight deflectometer tests) are essential in order to validate an adequate mechanical behavior of the recycled materials (Arm, 2001, Grégoire et al. 2009, Aurstad et al. 2009, Freire et al. 2010).

Considering the enormous variety of recycled materials and conditions of their application, it is advisable a thorough research based on experimental sections, instrumented and observed along the life cycle of the structures.

The National Laboratory for Civil Engineering (LNEC, Portugal), in cooperation with the Technical University of Lisbon (IST, Portugal), is carrying out the project SUPREMA – Sustainable Application of Construction and Demolition Recycled Materials (C&DRM) in Road Infrastructures. The main purpose of this project is to respond to the issues raised by the national and international technical community through the development of the research lines concerning the application of C&DRM as recycled aggregates in road pavement base and sub-base layers and in capping layers. The work plan includes a specific experimental programme, comprising laboratory and in situ tests on a reference natural aggregate: limestone, and several selected C&DRM: crushed concrete, crushed mixed concrete, crushed reclaimed asphalt and milled reclaimed asphalt (Freire et al. 2010).

The main objective of the paper is to present the most recent research of SUPREMA based on the instrumentation and observation of experimental tests sections. The aggregates used in the experimental sections were crushed mixed concrete (concrete and ceramic mixtures), reclaimed asphalt material (crushed asphalt and milled material) and limestone, as the reference material. The paper presents preliminary results from in-situ loading test series, performed by the Falling Weight Deflectometer (FWD), for deflection measurements of the base layer constituted by the recycled and natural aggregates. It was concluded that base layers stiffness with recycled aggregates is equal to or slightly less than the base layers stiffness of natural aggregates. These important findings encourage with confidence the recycling of C&DRM, provided that best practices of construction and of quality control are implemented.

2 EXPERIMENTAL SECTIONS

2.1 Materials

Integrated in a new industrial park dedicated to recycling activities involving waste from different origins (electric and electronic residues, wood, construction and demolition waste), located in the south of the metropolitan region of Lisbon, a zone was selected to implement the full-scale experimental sections.

Four experimental test sections were constructed in order to apply and evaluate the in situ behavior of different recycled aggregates and natural aggregate (Figure 1):

- crushed mixed concrete (Figure 1a);
- crushed reclaimed asphalt (Figure 1b);
- mix of 70% natural aggregate from crushed limestone and 30% milled reclaimed asphalt (Figure 1c);
- natural aggregate from crushed limestone (Figure 1d).

(a) Crushed mixed concrete

(b) Crushed reclaimed asphalt

(c) Mix of 70% natural aggregate from crushed limestone and 30% milled reclaimed asphalt

(d) Natural aggregate from crushed limestone

Figure1: Materials used in the experimental sections.

The composition of the recycled aggregates should be assessed according to the procedure laid out in standard EN 933-11 (CEN, 2009). For the case of the three recycled aggregates, Table 1 presents the composition of the different constituents for each material based on that methodology. The constituent's classification was performed by hand sorting particles of different constituents, exception made to the floating particles, and expressing the proportion as a percentage by mass. For the floating particles content the result is expressed as a volume by mass.

Regarding the constituents proportions, crushed mixed concrete belongs to class C of recycled aggregates covered by LNEC's specification E473 (LNEC, 2009). For reclaimed asphalt materials, the proportion of constituents does not allow them to fit in any class of this specification.

The grain size distribution of the materials was determined according to EN 933-1 (CEN, 2012), by the sieving method with washing aggregate for removing the clay particles and other aggregate finer particles, exception made to the milled reclaimed asphalt that was analysed without aggregate washing. The natural aggregate and the mixture of natural aggregate with milled reclaimed asphalt have more quantity of smaller size particles. On the other hand, crushed aggregates seem to be constituted by more coarse aggregate, mainly in the case of the crushed mixed concrete.

Table 1: Classification of the constituents.

Constituents	Crushed mixed concrete	Crushed reclaimed asphalt	Milled reclaimed asphalt
Rc (%)	68	19	0.1
Ru (%)	17	10	17
Ra (%)	1.9	69	83
Rb (%)	13	1.8	0.0
Rg (%)	0.3	0.0	0.0
X (%)	0.1	0.0	0.0
FL (cm^3/g)	0.6	0.0	0.0

Legend: Rc - Concrete, concrete products, mortar, concrete masonry units
Ru - Unbound aggregate, natural stone, hydraulically bound aggregate
Rb - Clay masonry units (i.e. bricks and tiles), calcium silicate masonry units, aerated non-floating concrete
Ra - Bituminous materials
Rg - Glass
X - Other: Cohesive (i.e. clay and soil), miscellaneous: metals (ferrous and nonferrous), non-floating wood, plastic and rubber, gypsum plaster
FL - Floating particles

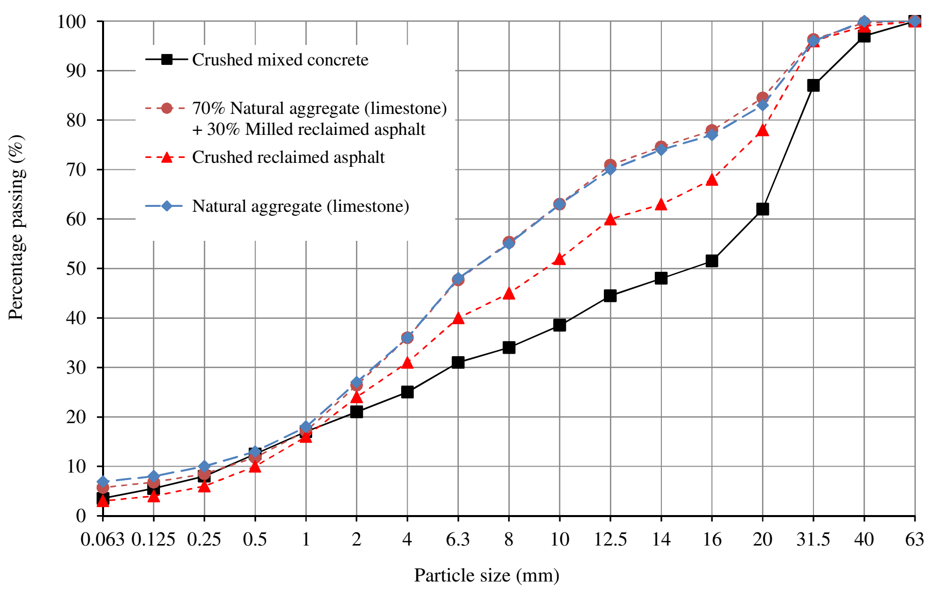

Figure 2: Grading curves of the materials used in the experimental sections.

Other laboratory tests were performed, in order to obtain chemical, geometrical, physical and mechanical properties of the materials. Leaching tests were also performed with the materials in order to verify their compliance with the legal limits of acceptance of waste for disposal in landfill (Freire et al. 2012).

2.2 Construction and loading tests

The pavement of the experimental sections is composed by a granular base layer of 30 cm thickness composed by the recycled materials. Construction procedures were similar for all the sections. Figure 3 shows the equipment used in the operations of spreading and compaction of the materials. In order to ensure an adequate compaction in the total depth of the base layer, the compaction was performed in two sub-layers: 18 cm and 12 cm. Each section covers an area of approximately 6×15 m^2.

Figure 3: Construction of the experimental sections.

The material used in each experimental test section was:

- Section 1: crushed reclaimed asphalt;
- Section 2: crushed mixed concrete;
- Section 3: natural aggregate from crushed limestone;
- Section 4: mix of 70% natural aggregate from crushed limestone and 30% milled reclaimed asphalt.

Test sections are located in a small embankment and they have a similar subgrade constituted by a sandy soil. A bituminous layer will be constructed as a final wearing course in all the experimental sections.

During the construction of the base layers, density and moisture content of the materials were controlled by in situ and laboratory tests.

The stiffness of the experimental sections was evaluated by loading tests performed by the FWD. These loading tests were carried out on the subgrade soil and on the base layer. Figure 4 shows the used equipment in operation. The deflections corresponding to an impact load of 30 kN, applied in a circular plate of 45 cm diameter, were measured for the following distances, in centimeters, from the center of the circular load area to the geophone position: 0 (D0), 30 (D30), 45 (D45), 60 (D60), 90 (D90), 120 (D120), 150 (D150), 180 (D180) and 210 (D210).

Figure 4: FWD tests.

3 RESULTS AND DISCUSSION

FWD tests consisted in two set of measurements:

– Deflection measurements on the subgrade soil
– Deflection measurements on the base granular layer

The first tests were important to evaluate the stiffness of the subgrade soil, including the embankment and in situ soil, as foundation of all the test sections, and to a better understanding of the granular base layer stiffness.

The FWD results related to the base layer of the four sections were analyzed. Figure 5 represents only the deflections corresponding to D0 and D120 measurements. From Figure 5, it could be concluded that, based on D0 deflections, there are differences in the deformability of the experimental sections. In Sections 1 and 2, the highest values of D0 deflections mean a lower stiffness. Even taking into account the limited number of FWD tests and some dispersion of the results, the main statistical functions were calculated for D0 measurements on the base layer.

Figure 6 represents graphically the values of minimum, average, percentile 85 (P85) and maximum of the D0 deflections for all the test sections. These statistical values confirm that Sections 1 and 2 seem to have lower stiffness (higher deflections) than the other sections. This conclusion must also take into consideration the stiffness of subgrade soil, evaluated in these tests by D120 deflections (Figure 5).

In general, FWD results show that base layers constructed with crushed mixed concrete and reclaimed asphalt have exhibited the lowest stiffness.

Finally, the layer composed of a mixture of 70% natural aggregate and 30% milled reclaimed asphalt seems to have a similar stiffness to the layer consisting of natural limestone aggregate.

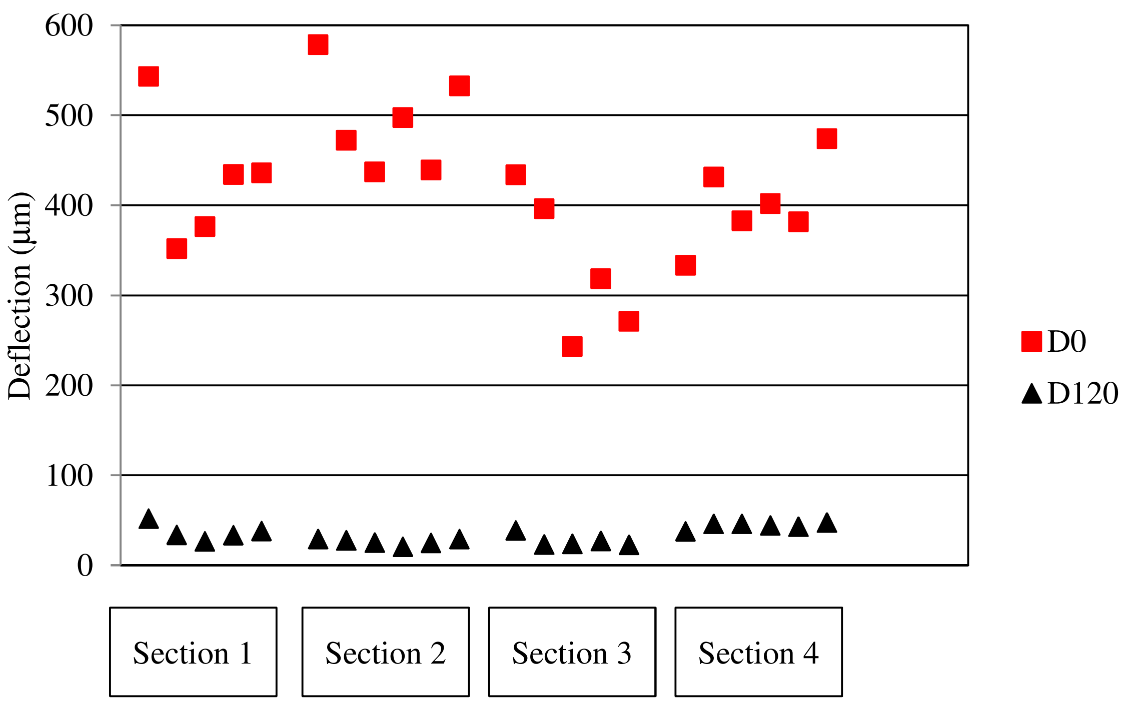

Figure 5: Deflections – D0 and D120 – measured on the base layer.

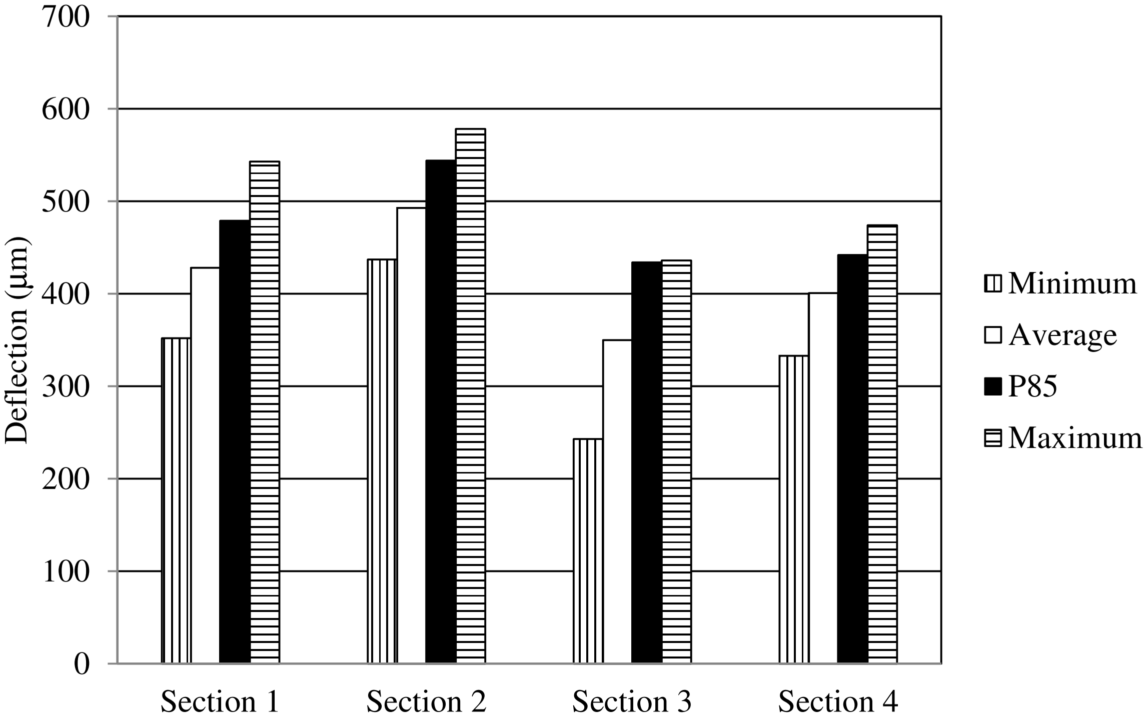

Figure 6: Statistical values for the deflection D0 measured on the base layer.

4 CONCLUSIONS AND FURTHER RESEARCH

This paper describes a research study performed in experimental test sections, consisting on the evaluation of the structural response of recycled materials used in unbound granular layers by in-situ loading test series performed by FWD.

Recycled aggregates used in the granular base of experimental sections were selected from construction and demolition materials (crushed concrete and ceramic mixtures, and reclaimed asphalt material – crushed asphalt and milled material). Crushed limestone was also used as a reference material.

The analysis of the in situ load tests confirmed that recycled materials showed a different behavior from natural material. However, it could be considered that in general all recycled materials have demonstrated an acceptable performance, even in the case that a higher deformability was observed.

These conclusions should be confirmed by further research. During the construction, experimental sections were instrumented with strain gauges and load cells, placed in pavement layers (bituminous and granular layers) and subgrade soil. The backanalysis of FWD tests in combination with instrumentation measurements will be essential in order to achieve a more accurate validation of the bearing capacity of the recycled materials used in the unbound granular layers of the experimental sections.

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