USE OF CONSTRUCTION AND DEMOLITION RECYCLED MATERIALS (C&DRM) IN ROAD PAVEMENTS VALIDATED ON EXPERIMENTAL TEST SECTIONS

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ABSTRACT
The construction activity usually generates large amounts of waste from different sources and processes. Due to the increasing shortage of space for landfill implementation and the costs associated with waste control regulations, derived from its ever increasing environmental protection requirements, the most desirable alternative is the reduction of construction and demolition waste volumes by means of their reuse and recycling.
A research project, SUPREMA - *Sustainable Application of Construction and Demolition Recycled Materials (C&DRM) in Road Infrastructures*, is being developed by the National Laboratory for Civil Engineering (LNEC), and by the University of Lisbon (IST). This project seeks to contribute to the sustainable implementation of C&DRM in road pavements by improving the knowledge of the physical, mechanical and environmental behaviour of these materials when placed as aggregates in unbound pavement layers.
Besides a general presentation of the research project and the construction procedures of a test pit structure where four different materials were applied, this paper presents some results related to the characteristics of the studied materials, supported by laboratory and by *in situ* tests performed with the FWD in the test pit structure. It was concluded that all materials demonstrate an acceptable structural performance.

Keywords: Sustainability, waste; construction and demolition recycled materials; road pavements; experimental test sections.

INTRODUCTION
Large amounts of waste are generated in construction and demolition activities. This very waste can derive from different sources and processes such as the cleaning of the work site and earthworks, discarded materials during construction and demolition operations and maintenance and rehabilitation of existing constructions.
The reuse and recycling of Construction and Demolition Waste (CDW), in various applications in civil engineering works, are the best solutions for a technical, economic and environmentally efficient management of these resources.
The incorporation of large amounts of these materials in the unbound layers of road pavements represents one of the foretold applications as it significantly contributes to a more sustainable construction and rehabilitation of road pavements.
As such, intensive research supported by experimental work is essential in order to overcome empirical approaches in the design and construction using recycled aggregates for purposes of transportation infrastructures and geotechnical structures [1, 2, 3].
Since 2010, a research project, SUPREMA - *Sustainable Application of Construction and Demolition Recycled Materials (C&DRM) in Road Infrastructures*, is being developed by the National Laboratory

for Civil Engineering (LNEC), in association with the University of Lisbon (IST). The main research interests of the SUPREME project are as follows:

1. Evaluation of the geomechanical and geoenvironmental characteristics of different types of C&DRM, as a function of their origins, sorting methodology and final composition.
2. C&DRM performance as unbound granular materials and their comparison with natural materials.
3. Determination of the parameters to be used in pavement design, considering C&DRM application.
4. Study of the construction aspects to be developed and applied, as a function of C&DRM type, to unbound granular base and sub-base courses, and capping layers.

Following the first results of SUPREMA project presented in [4], *in situ* tests were performed on experimental test sections constructed with the application of C&DRM on the unbound granular layers. 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.

This paper presents the applied instrumentation and some 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.

EXPERIMENTAL STUDY

Materials characterisation

Four different materials were selected and applied at the experimental test sections constructed in order to evaluate the *in situ* behaviour (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).

The experimental test sections were constructed at a new industrial park dedicated to recycling activities involving waste from different origins, located in the south of the metropolitan region of Lisbon.

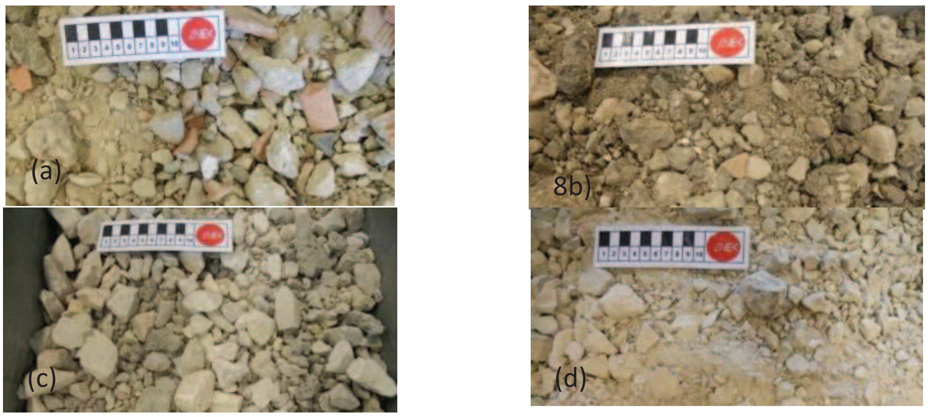

Figure 1 – Studied materials

The grain size distribution of the studied materials was determined according to EN 933-1 [5], by the sieving method with washing aggregate for removing the clay particles and other aggregate smaller particles. However, the milled reclaimed asphalt was analysed without aggregate washing. The natural aggregate and the mixture of natural aggregate with milled reclaimed asphalt have the greatest amount of smaller size particles. On the other hand, crushed aggregates seem to be constituted by a coarser aggregate, mainly in the case of the crushed mixed concrete (Figure 2).

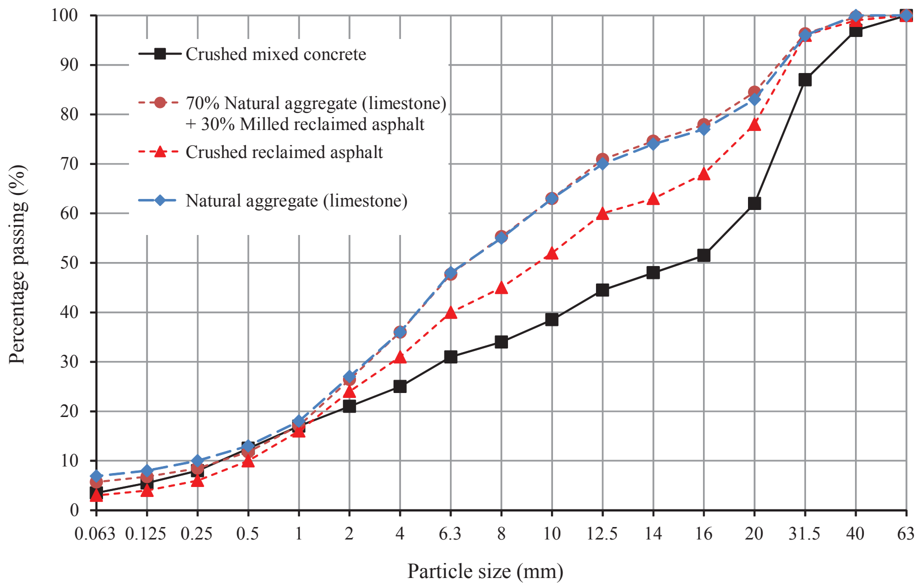

Figure 2 – Grading curves of the studied materials

The constituents of the studied recycled aggregates were analysed according to the procedure laid out in EN 933-11 [6] and are listed in Table 1. According to its constituents' proportions, crushed mixed concrete, belongs to the C class of recycled aggregates as stated by the Portuguese LNEC Specification E473 [7]. For reclaimed asphalt materials, the proportion of their constituents does not allow them to fit in any class of this specification.

Table 1 – Classification of constituents

Constituents	Crushed mixed concrete	Crushed reclaimed asphalt	Milled reclaimed asphalt
Rc [%]	67	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.

Other laboratory tests were performed in order to obtain chemical, geometrical, physical and mechanical properties of the materials. Leaching tests were also performed on the materials with the objective of verifying their compliance with the legal limits of acceptance of waste for disposal in landfill [4].

Construction and instrumentation

The experimental pavements are made of a granular base layer 30 cm thick consisting of recycled and natural materials. Construction procedures were similar for all sections. Figure 3 shows the geometry of the experimental test sections. In order to ensure an adequate compaction along the total depth of the base layer, the compaction was performed in two sub-layers: 18 cm and 12 cm. Each test section has an area of approximately 6×15 m^2.

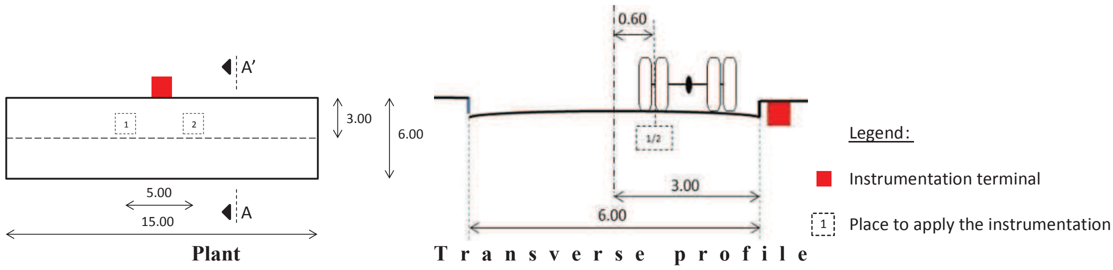

Figure 3. Geometry of the experimental test sections

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 comprised of sandy soil. A bituminous layer was 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 testing. The quality control reference of the aggregates' compaction was the Modified Proctor test.

The instrumentation of the experimental sections comprised of: strain gauges in the bituminous layer and the subgrade soil; load cells in the subgrade soil; thermocouples in the bituminous layer in order to temperature measurements. The instruments were deployed during construction, and specific care was required during installation regarding the movement of people and machines. The placement of all the instrumentation was georeferenced. Figure 4 shows some of the instrumentation, at the top of the sub-grade layer (Figures 4(a) and (b)) and at the base of the bituminous layer (Figure 4(c)).

Figure 4 – Applied instrumentation

STRUCTURAL EVALUATION

The structural behaviour of the experimental pavements was evaluated by loading tests performed by the FWD. These loading tests were carried out on the sub-grade soil and on the base layer. The deflections, corresponding to an impact load of 30 kN and applied in a circular plate of 45 cm in diameter, were measured for the following distances, in centimetres, from the centre 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).

The FWD results related to the base layer of the four sections were analyzed. Figure 5 represents the deflections corresponding to D0 and D120 measurements. It was 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 imply lower stiffness. *Despite* the limited number of FWD tests

and the dispersion of the results, the main statistical functions were calculated for D0 measurements on the base layer.
Figure 6 graphically represents the minimum, average, percentile 85 (P85) and maximum values 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 sub-grade 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 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 composed by the natural limestone aggregate.

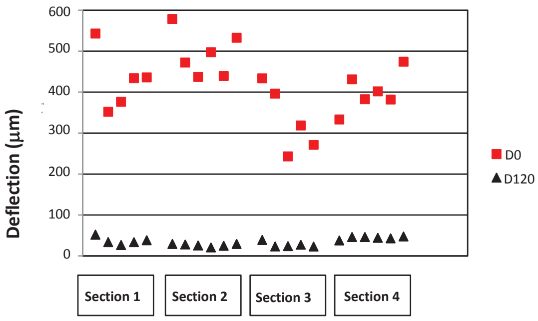

Figure 5. Deflections – D0 and D120 – measured on the base layer

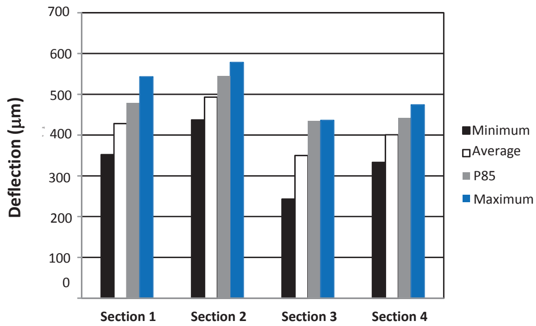

Figure 6. Statistical values for the deflection D0 measured on the base layer

FINAL CONSIDERATIONS

This paper presents a research study performed in experimental test sections, the applied instrumentation and the evaluation of the structural response of recycled materials used in unbound granular layers by FWD loading test series.
Recycled aggregates used in the granular base of experimental sections were selected from construction and demolition materials: crushed concrete and ceramic mixtures; reclaimed asphalt material – crushed asphalt and milled material. Crushed limestone was also used as a reference material.
During construction, experimental sections were embedded with strain gauges and load cells placed in the pavement structure and sub-grade soil.
The analysis of the FWD tests confirmed that recycled materials show a different behaviour from natural materials. However, it could be considered that, in general, all recycled materials demonstrate an acceptable performance, even in the case where higher deformability was observed.
It can also be concluded that the base layers' stiffness with recycled aggregates is equal to or slightly lower than the base layers' stiffness when using natural aggregates. These important findings encourage the recycling of C&DRM, provided that the best practices of construction and of quality control are implemented.
The conclusions of this paper must be backed by further research. The back analysis of FWD tests associated with instrumentation measurements will be crucial in order to achieve a more accurate

validation of the bearing capacity of the recycled materials applied in the unbound granular layers of the experimental sections.

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