Contribution to the mechanical characterization of unbound sub-base and base road pavement layers containing reclaimed asphalt pavements

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Abstract:
The main objective of this work was to contribute to the study of the use of construction and demolition recycled materials at pavement construction and rehabilitation. The study focused on evaluating the physical and mechanic behaviour of a mixture composed by 30% recycled aggregates from reclaimed asphalt pavement (BET-F(T)) and 70% natural grinded aggregate mixture with extensive grain size (ABGE(T)) when submitted to state conditions of base and sub base pavement layers. This analysis was performed based on a repeated load triaxial test. Permanent deformations and resilient behaviour was studied for temperatures of 20, 30 and 40ºC and compaction degrees of 95 and 100%. The results shows that the axial permanent deformation obtained is comparable with results found on natural aggregates and the resilient behavior is comparable to results obtained, from other authors. It is concluded that this material is a potential candidate for use on structural pavement layers.

Keywords: Mechanical behaviour, repeated triaxial load test, construction and demolition recycled materials, road construction.

1. Introduction

Roads are one of the biggest assets in any country. Construction and rehabilitation of roads demand a large volume of crushed rock as granular layers, stabilized granular layers, and aggregates for asphalt production. The constant use of natural resources presents evident negative environmental impacts at several levels. For instance, there is a conversion of land use from undeveloped or agricultural land, to a hole on the ground empowering geological problems and a bigger degradation of land value. There is a growing concern for environmental impacts that pressures political power to create laws and associated taxes for use and waste of natural resources. The use of recycled construction and demolition waste is a way of reducing waste materials and to avoid the payment of taxes associated with these procedures. To use recycled materials is necessary to understand its behaviour when submitted to final conditions.

Throughout Europe there is pressure to increase the use of alternative materials in construction applications such as roads.

From the point of view of mechanical performance, uncertainties about alternative materials remain, especially with respect to the long-term performance. The nature and composition of alternative materials is often significantly different from that of natural aggregates, and existing tests for natural aggregates may not be appropriate. As an alternative material for use in road structure, the knowledge of the structural characteristics is limited. In order to broaden the use of RAP study's regarding the material behaviour are justified.

2. Methods and Materials

A research was conducted in order to understand which proper regulated test presents a reliable way to simulate the state of an aggregate mixture of a base road layer.

This research lead to the cyclic load triaxial test.

The cyclic load triaxial test performed follows the methods and procedures regarding the Standard EN 13286-7: 2004. This test is conceived to simulate the conditions of the unbound materials in pavement layers subjected to moving loads concerning stress states and conditions. The method B of the standard was adopted and consists of the constant confining pressure method in which only cyclic axial loading and constant confining pressure are performed.

2.1. Material description

The materials used at the experimental study where chosen at the scope of the investigation project "Suprema - Sustainable application of Construction and Demolition Recycled Materials (C&DRM) in road infrastructures" developed by LNEC in association with Instituto Superior Técnico.

A mixture composed by 30% recycled aggregates from reclaimed asphalt pavement (BET-F(T)) and 70% natural grinded aggregate mixture with extensive grain size (ABGE(T)).

Aggregate classification

The classification and identification of the C&DRM mixture components, was made according to the methods recommended in the standard EN 933-11:2009.

The reclaimed asphalt pavement obtained mixture is described in Figure 1.

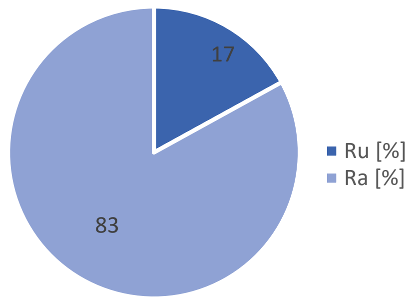

Figure 1 - Composition the recycled aggregates from reclaimed asphalt pavement mixture (BET-F(T)) regarding the EN 933-11:2009 Standard.

Were:

Ra – Bituminous material;

Ru – Unbound aggregates, natural stone, hydraulic binder treated aggregates.

2.2. Particle size distribution

The analysis of the particle size distribution characteristics of the C&DRM samples used was done according to the Standard NP EN 933-1:2000 and EN 933-1:1997/A 1: 2005.

For this work it is important to take in consideration results for ABGE(T) and BET-F(T) as well as the required results by Estradas de Portugal Specifications (EP, 2010) of base and sub-base granular layers.

2.3. Equipment description

The equipment is designed for cylindrical specimens with two different dimensions: i) 203 mm diameter and 410 mm high; ii) 152 mm diameter and 310 mm high. The mounting of these two specimen sizes requires a different configuration. In Figure 2 is a view of the triaxial cell base and the mechanical equipment needed. In the case of this study, specimens with ii) sized specimens were tested and it is possible to identify the following constituent parts:

- [1] – Base cell;
- [2] – Load cell;
- [3] – Top and Base end platen;
- [4] – Axial deformation transducers;
- [5] – Radial Deformation transducer;
- [6] – Load Piston

Figure 2 - Interior triaxial cell base equipment

2.4. Data acquisition software

The software used to control the equipment works with a LabVIEW graphic tool under a MS Windows platform.

BridgeLab is the software tool used to control the testing equipment. It allows the user to access reports with data obtained during the test in real time.

This tool is composed of two distinguished parts, real time machine control (RTC: Real Time Core) and its supervision.

The software allows a manual and an automatic mode. The manual mode consists of a direct control of the hydraulic piston witch gives a perception of the equipment response and can be used for calibration purpose The automatic mode consists of the application of a predefined repetitive movement and it is used at the real test.

2.5. Specimen preparation

The preparation consists in several steps: material preparation, mixing and moistening, compaction and test specimen wrapping.

The mixture was set at a proportion of 30% recycled aggregates from reclaimed asphalt pavement

(BET-F(T)) and 70% natural grinded aggregate mixture with extensive grain size (ABGE(T)).

The compaction test adopted, to achieve the optimum water content, was the vibrating hammer – 2nd method EN 13286-4 using as reference the results of Proctor test NP EN 3286-2.

The specimens were compacted at the total of 6 layers of 30 cm each, using a vibration process. The apparatus used includes the cylindrical metal mold with a membrane designed to avoid water loss and a detachable baseplate.

2.6. Repeated load triaxial test

The tests were conducted under controlled temperature for different compaction degrees in order to proper describe the material´s behavior under different possible situations and therefore perform a much more complete study.

Six specimens were prepared according the method described. The temperatures chosen were 20, 30 and 40ºC in order to simulate the temperature range that subbase layer materials are exposed. The degrees of summarization chosen were 95% and 100%.

The maximum stress level was selected for the conditioning and the subsequent stress as a high stress level with a maximum deviator stress σd=340 kPa.

- Study of permanent deformations

The conditioning started by applying an initial stress, $\sigma_3 = 70\ kPa$ followed by 20.000 cycles of cyclic deviator stresses from $\sigma_d = 0$ to $\sigma_d = 340\ kPa.$

- Study of resilient behaviour

The procedures followed the European Standard. 100 cycles were performed for each stress path with confining pressures of 20 kPa to 70 kPa and $\sigma_d = 0$ to $\sigma_d = 340\ kPa$.

During the testing procedures, it was found that the equipment worked better if the application of the strain paths in an inverse order. This resulted in problems associated with the reconditioning of the material and the resilient modulus do not present significant changes when decreasing the maximum deviator stress.

3. Results & Discussions

For each mixture/temperature combination, permanent deformations and resilient behavior were tested. The permanent deformation study consisted of 2 tests of 20.000 cycles and the resilient behavior consisted of 20 tests with 100 cycles. All specimens were prepared with 4% water density and performed between 0,5 and 1,0 Hz (cycle/second).

3.1. Study for permanent deformations

The readings recorded were at the first 20 cycles followed by readings between 50 and 61, 88 and 111, 200 and 211, 400 and 411, 1000 and 1011, 2500 and 2511, 5000 and 5011, 7500 and 7511, 10000 and 10011, 12.500 and 12.511, 15.000 and 15.011, 17.500 and 17.511 20000 and 20011 as shown in Figure 3 .

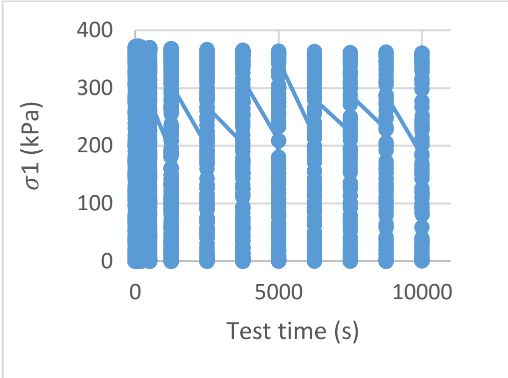

Figure 3 - σ_1 readings at T30ºC, 100%

An example of the readings obtained for the axial deformation of the test performed at T=20ºC and CD=95% is illustrated in Figure 4 . It is possible to visualize the course of the loading and the advancing of the axial deformation with the cycles

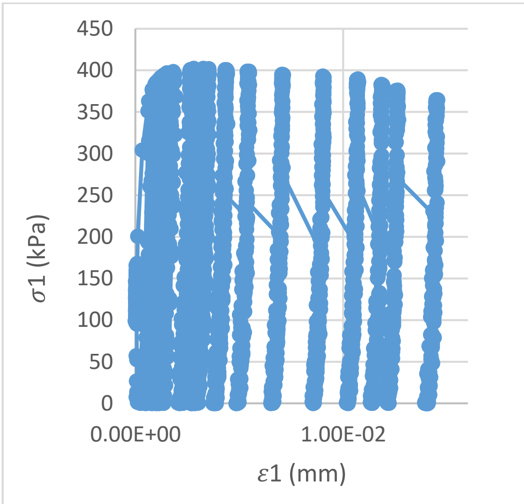

Figure 4 - Average axial deformation at 20.000 cycles, T20ºC, 95%

The progression of the permanent deformations can be compared and visualized in Figure 5.

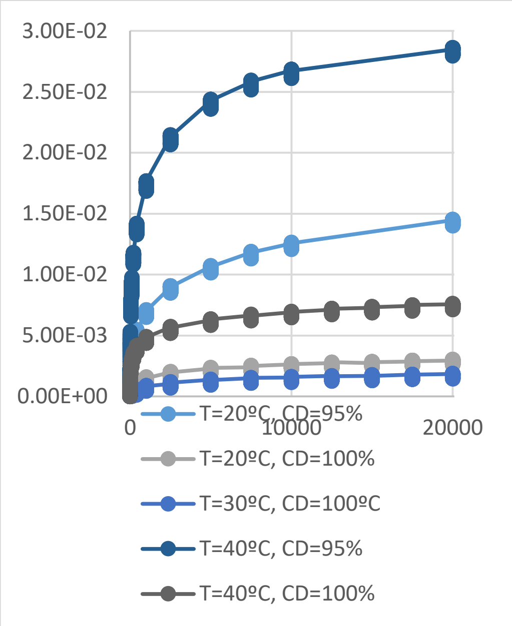

Figure 5 - Progression of the axial deformation at each condition

It is possible to conclude that the Compaction degree influences directly the permanent deformation.

At 20000 cycles, the progression of the axial deformation show a tendency to stabilize, but it is possible to state that 20.000 cycles are not enough to eliminate the permanent deformations of this material.

The results for the permanent axial deformation of the tested specimens are presented at Table 1.

Table 1 - Permanent axial deformation

	ε_p (m)	% ε_p
T=20º and CG=95%	$1{,}40 \cdot 10^{-2}$	4.52
T=20º and CG=100%	$2{,}70 \cdot 10^{-3}$	0.87
T=30º and CG=95%	-	-
T=30º and CG=100%	$1{,}88 \cdot 10^{-3}$	0.61
T=40º and CG=95%	$2{,}86 \cdot 10^{-2}$	9.23
T=40º and CG=100%	$7{,}60 \cdot 10^{-3}$	2.45

When comparing obtained results, in Figure 6, it is possible to observe that for the same temperature and moisture, compaction degree directly influences the permanent axial deformation. For higher degrees of compaction less permanent deformation is obtained. Temperature also represents a direct influence in deformations and for higher temperatures, the influence of compaction degree is even more influencing.

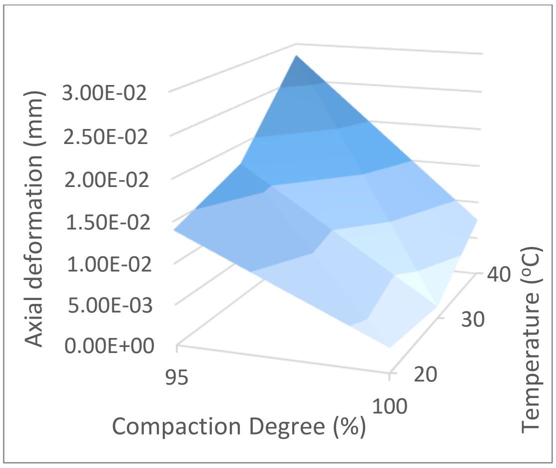

Figure 6 - Permanent deformation, comparison between tests

For 100% compaction degree, this material showed permanent deformations of 0.87, 0.61 and 2.45%. These values are comparable to results obtained in studies performed with limestone and granite.

At a study, using a repeated triaxial load equipment with cylindrical specimens 150 x 320 mm, the permanent deformation obtained varied between 0.4 and 1.4% for limestone and between 1.2 and 2.4% for granite (Conceição Luíza, et al, 2011).

This shows that the permanent behaviour of this material can be compared with well know materials used and base and subbase pavement layers.

3.2. Study of resilient behaviour

Due to the inverted procedure, the resilient modulus, obtained in the first experiment, are very similar to the following tests performed at lower stress paths. Due to this, the analysis was performed only for the stress path with σ3 = 70 kPa and 0 < σd ≤ 340. 100 cycles were performed at these tests.

The resilient modulus values were calculated in each test regarding the 10 last cycles. With this procedure was possible to ensure, no permanent deformation were entering the evaluation of the resilient behavior of the material.

The recordings were made, in each test, at the first 20 cycles, between cycle 50 and 61, 88 and 102, which follows the suggested method at the European Standard and is represented at the example in Figure 7.

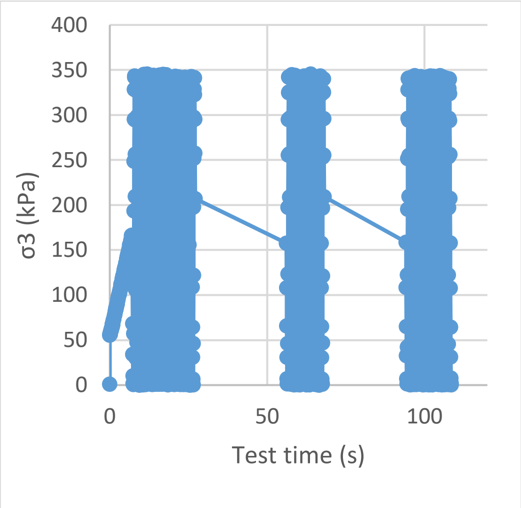

Figure 7 - σ_1readings at T20C, 95% - Resilient Behaviour

In order to easily demonstrate the variation of axial deformations of the material, Figure 8 represents an example of the axial deformation of the specimens for 100 cycles with 0 < σd < 340 kPa and σ1=70kPa. Figure 9 represents an example of the axial deformation of the specimens at 10 cycles and the values used to obtain the resilient module.

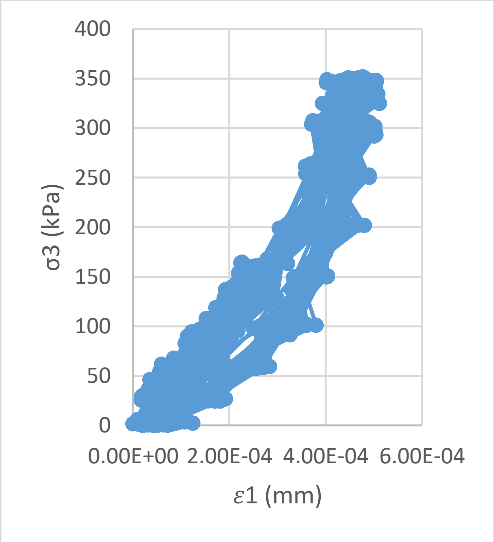

Figure 8 - Axial deformation at 100 cycles – T=40º, CD=100%

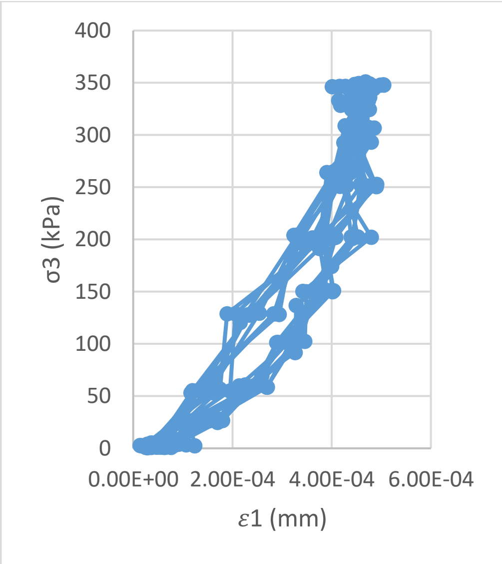

Figure 9 - Axial deformation at 10 cycles – T=40º, CD=100%

The obtained resilient modulus was a result of an average between the calculated values of the 10 cycles. In Table 2 it is possible to see the relations between temperature, compaction degree and resilient modulus performed for the selected stress path.

Table 2 - Resilient Modulus Results

Compaction Degree (%)	Temperature (ºC)	Resilient Modulus (MPa)	Deviator stress σ_d (KPa)
95	20	737.9	0 - 340
	30	644.8	
	40	518.9	
100	20	-	
	30	958.4	
	40	833.2	

When comparing the resilient modulus obtained at the different tests, Figure 9. it is possible to observe that the resilient modulus decreases at higher temperatures and increases at higher compaction degree.

In Figure 10 is represented a relation between Resilient Modulus, Temperature and Compaction Degree. Temperature and Compaction Degree, represent approximately the same influence in Resilient Modulus.

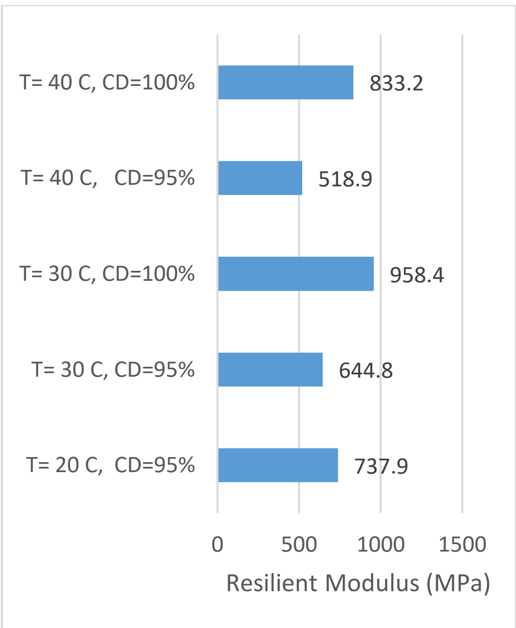

Figure 10 - Resilient Modulus Comparison between tests

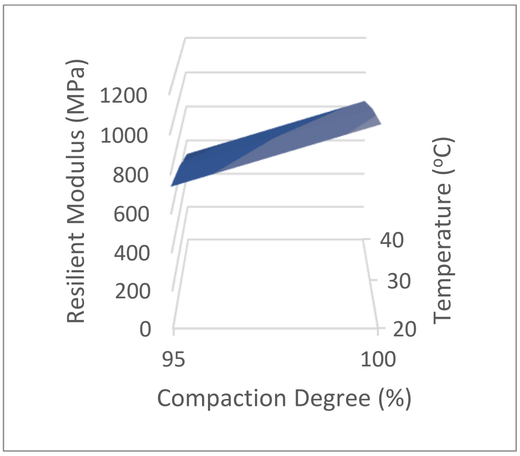

Figure 11- Resilient Modulus relations

The resilient modulus values obtained for the selected stress path, $0 < \sigma_d < 340\ KPa$, are comparable to values obtained in previous studies.

A. Gomes Correia, G. Grégoire, B. Dethy & J. Detry, 2009, performed triaxial test with Steel Slag and crushed concrete aggregate. For the referred stress path, limestone presented resilient modulus of 400 MPa, crushed concrete presented values 470MPa and steel slag with 650 MPa. This leads to the conclusion that this material may be eligible for use in base and sub base pavement layers.

3.3. Mechanical Behaviour Model

For the resilient modulus modelling, some behaviour models (Lekarp et al., 2000; NCHRP, 1998) generally used in modelling of the mechanical behaviour of granular materials were adjusted to the test results, namely the models Dunlap, k–θ (ICE, 2011)

The model intended to use at this study was the following:

1. $E_r = k_1 \theta^{k_2}$.

Where θ is the first invariant of stress ($\theta = \sigma_1 + \sigma_2 + \sigma_3$). k_1 and k_2 are material constants.

In order to calculate the model, a chart with resilient modulus versus the first invariant of stress (θ) must be obtained at each stress path. Values of K_1 and K_2 would be obtained at a regression.

With this methodology it is possible to define the material representative values K_1 and K_2 for each tested temperature.

The aspect referred regarding the application of an inverse methodology of stress paths applied at each specimen, lead to problems associated with the reconditioning of the material and the resilient modulus did not present significant changes when decreasing the maximum deviator stress. For this reason it was not possible to calculate the resilient modulus for different stress paths at each test and consequently calculate K_1 and K_2 values.

4. **Conclusion**

The dissertation focused on C&DRM use at unbound pavement layers namely base and sub base pavement layers. In order to access if a certain material can replace well known natural aggregates it is important to study mechanic and physical characteristics when submitted to the conditions verified at the designated pavement layers. Repeated load triaxial tests were conducted with mixture composed by 30% recycled aggregates from reclaimed asphalt pavement (BET-F(T)) and 70% natural grinded aggregate mixture with extensive particle size distribution (ABGE(T)). This test was chosen once it simulates real state conditions.

Two main studies were made for the selected material: Study of permanent deformations and resilient behavior. In order to better describe the material, the tests were performed at 20, 30 and 40 degrees Celsius and for two compaction degrees: 95% and 100%.

At the study of permanent deformations, due to technical issues, it was not possible to retrieve data from the test performed at 30ºC and compaction degree of 95%. For the same reason, at the resilient behavior study, it was not possible to retrieve data from the test performed at 20ºC and compaction degree of 95%.

At the resilient behavior study, the equipment showed problems in the application of low stress paths at first. The solution found was to initiate the study in reverse order. This resulted in the reconditioning of the material and the resilient modulus did not present significant changes when decreasing the maximum deviator stress. For this reason, the data discussion focused exclusively at the stress path characterized by $0 < \sigma_d < 340\ KPa$.

The axial permanent deformation obtained is comparable with results found on natural aggregates and for higher degrees of compaction less permanent deformation is obtained. Temperature also represents a direct influence in deformations and for higher temperatures, the influence of compaction degree increases.

To what concerns to the resilient behaviour, the resilient modulus obtained is comparable to results obtained with limestone, crushed concrete and steel slag. It was possible to conclude that resilient modulus decreases at higher temperatures and increases at higher compaction degree and temperature and compaction degree, represent approximately the same influence in Resilient Modulus.

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