STUDY METHODOLOGY TO PROMOTE A NON-TRADITIONAL MATERIAL INTO A CONSTRUCTION MATERIAL FOR TRANSPORTATION INFRASTRUCTURES AND GEOTECHNICAL WORKS. THE EXAMPLE OF THE PROCESSED STEEL SLAGS OF NATIONAL IRON STEEL COMPANIES

S. M. REIS FERREIRA[1,*], A. GOMES CORREIA[2], A. ROQUE[3] and A. CAVALHEIRO[4]

[1] Geomec Engenheiros Consultores, Belo Horizonte, Brazil.

[2] University of Minho, Guimarães, Portugal.

[3] Nacional Laboratory of Civil Engeneering, Lisboa, Portugal.

[4] Portuguese Iron Steel Company, Seixal, Portugal.

*Corresponding author: sandra@geomec.com.br, tel: +55 3132221970, fax: +55 3132137204

Keywords: Steel slag, natural materials, recycled materials, performance-based tests, index tests, environmental properties, lysimeter, full-scale field trial

Abstract

In Portugal, and also at international level, preventing the production of a significant number of different types of waste, where are included the steel slags is still unfeasible. Therefore, there is strong pressure to use industrial byproducts and recycled materials in the construction of transportation infrastructure and geotechnical works. The reuse of these materials positively affects the environment by reducing deposits and preserving raw materials.

This paper presents the study methodology involving the environmental and geomechanical characterization and field monitoring that was used for evaluating the application of Portuguese processed steel slags in transportation infrastructures and geotechnical works.

From the test results it was concluded that these materials fulfill the requirements of the Specification of the Portuguese Roads Administration based in empirical tests. It was also concluded that performance laboratory tests results show a much better material performance than the results based in empirical tests (Los Angeles and micro-Deval). In addition, this material when compared with results of mechanical tests of natural unbound granular materials used in road construction show better mechanical performance. These test results prove that the mechanical laboratory properties must be determined by performance laboratory tests, once the empirical tests could not predict the real mechanical behavior of these materials.

Additionally, leaching test results show that this byproduct is inert and became titled "Inert Steel Aggregates for Construction (ISAC)". These laboratory conclusions were validated in a full-scale field trial, where were used raw materials and ISAC, by end performance testing.

1- INTRODUCTION

At Portugal there are two Iron Steel Companies (ISC), one is located at Seixal and the other at Maia, and currently operating with electric arc furnaces. The two ISC produced about 250,000 tons of black steel slag that are transformed into inert aggregates. Details of its industrial process could be found at [1].

In Portugal, and also at international level, preventing the production of steel slags is still unfeasible. Once that, a waste management strategy should favor the exploitation of its potential, namely through re-use solutions, a Research and Development Project (R&D) was undertaken in Portugal (2005-2009), which was intended to study the re-use of processed steel slag, actually named Inert Steel Aggregate for Construction (ISAC), in the construction of transport infrastructures and geotechnical works.

It is, therefore, necessary to demonstrate that the use of ISAC, instead of natural materials, will assure, at least, the same construction quality and long term performance. On this basis, the R&D National Project gave priority to laboratory performance-based tests for engineering properties, once that there is some common understanding that many of the engineering test methods, used for natural materials, may not predict true field performance when applied to non-natural materials. It also examines environmental properties (leachability) which are relevant for non-natural materials, as well as field tests to check the laboratory test results.

This paper describes the study methodology that was used to promote the ISAC of national ISC into a construction material.

2- MATERIALS AND METHODS

The laboratory study of ISAC started with the geotechnical current test procedures to obtain geometrical, physical and mechanical index properties (LA, MDe, CBR). The aim of this study was mainly to check if the ISAC meet the specifications of the Portuguese Roads Administration.

As already mentioned the laboratory performance-based tests was identified as a priority, and they covered four aspects of geotechnical behaviour: compressibility and ultimate strength under monotonic loading (to evaluate the application of ISAC in embankments), resilient behavior (stiffness) and susceptibility to the build-up of permanent deformation due to repeated loading (to evaluate the application of ISAC in transportation infrastructures, namely the structural pavement layers, capping and base layers of pavements).

The compressibility of ISAC was study by means of Uniaxial Compression Ttest, UCT (Figure 1a). The strain was measured externally by three deflectometers and the force by one dynamometric ring. To study the properties of ultimate shear strength Monotonic Triaxial Tests, MTT (see Figure 1b) were carried out. A standard pressure transducer and a sensitive load cell located inside the triaxial cell or a dynamometric ring are used to measure the boundary stresses (cell and deviatoric stresses). In this test the axial strains were externally measured using a Linear Displacement Transducer (LVDT).

The resilient behaviour (stiffness) was studied by Precision Triaxial Tests, PTT (Figure 1c). In this test a standard pressure transducer and a sensitive load cell located inside the triaxial cell were used to measure the boundary stresses. The axial and radial strains were locally measured using three vertical LDT (Local Deformation transducer) and one horizontal LDT, which were able to record strains from 10^{-6} to 10^{-2}.

The susceptibility to the build-up of the permanent deformation was evaluated by Precision Triaxial Cyclic Test, PTCT (Figure 1d). As for the PTT, axial and radial strains were measured using vertical and horizontal LDT. The force was applied by an axial servo-actuator of 50kN installed inside the frame, the confining pressure was controlled by standard pressure transducer and the maximum testing frequency was equal to 5 Hz. The test procedure followed the test protocol described at EN Standard 13289-7 (2004) for constant confining pressure at high stress levels.

All these tests were done at compacted samples for a very dense state because this state is representative of typical compacted pavement layers. More details could be found at [1, 2].

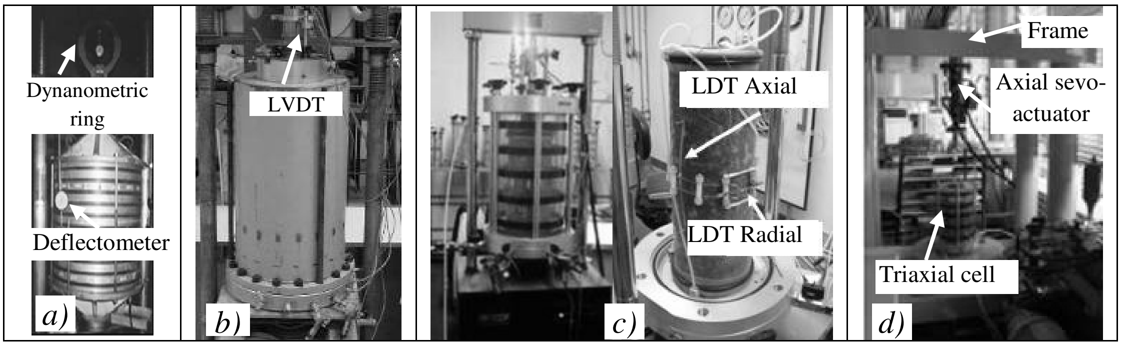

Figure 1: Laboratory performance-based tests – a) UCT; b) MTT (ϕ = 300mm); c) PTT (ϕ = 150mm) and detail of local instrumentation; b) PTCT.

The leachability potential of ISAC was studied on samples collected from ISC Maia. In the period when the tests were performed, the applicable Portuguese legislation in force was the Decree-law Nº 152/2002, 23 May, and, therefore, the German standard DIN 38414-S4 was adopted rather than the European Standard EN 12457-Part 2 or Part 4, defined in the Portuguese legislation that is presently in force (Decree-law nr. 183/2009, 10 August).

In the field, the assessment of the mechanical and environmental performance of the ISAC was carried out at the construction of a full-scale field trial, with about 60 m length and 3 m height, integrated in a national road in use, built at km 13+600 of National Highway EN 311, linking Fafe to Cabeceiras de Basto, to the north of Oporto (< 100 km), with three distinct sections. In one section, only natural materials were used (at embankment and capping layer, granitic residual soil (GRS) and at base layers granite aggregate, GA), in another section only ISAC was used (at embankment, capping and base layers of pavement) and in the third section GRS was used (at embankment and the capping layers of pavement) and ISAC (used at base layer). More details could be found at **Erro! Fonte de referência não encontrada.**1, 2].

The assessment of mechanical behaviour was done during full-scale field trial road construction by devices which measure in-situ stiffness by spot tests (Soil Stiffness Gauge, SSG, Light Falling Weight Deflectometer, LFWD, Static Plate Load Test, SPLT, Wheel Load Test, WLT, Falling Weight Deflectometer, FWD) and by continuous monitoring (Portancemètre).

The SSG (Figure 2a) is an instrument lightweight and the foot rest directly on the soil. A mechanical shaker, which is attached to the foot, shakes the SSG from 100 to 196Hz producing 25 different frequencies and generating a force of 9N. A microprocessor computes the stiffness for each of the 25 frequencies, and the average value.

The LFWD (Figure b) is a portable device and consist of a loading device that produces a defined load pulse, a loading transducer and at least one geophone sensor to determine the deflection of the centre of the plate. The Young´s modulus is calculated from load and pulse deflection.

The SPLT (Figure 2c) consist in the application, after a preload, of successive loading cycles on a plate with stiffness and diameter standard. The goal of the test is to assess the deformation and strength characteristics of the soil and to determine the Young´s Modulus.

The WLT allows the measuring pavement surface deflections that are measured with dial gauge, strategically located at benkleman apparatus (Figure 2d). The benkleman apparatus is designed to determine the deflection of a flexible pavement of road surface under moving wheel loads. The free end of the benkleman apparatus carries a dial gauge (LVDT at this study) to record the deflections while the other end is kept on a stable platform.

The FWD generates a load pulse by dropping a weight onto a damped spring system mounted onto a circular loading plate. The resultant deflection bowl of the pavement is accurately determined from measurement of peak deflections at the centre of the loading plate and at several radial positions by a series of geophones (Figure 2e).

The Portancemètre (Figure 2f) is an instrument developed by the Centre d'Études Techniques de l'Équipment in France. This equipment applies a load at a frequency 35Hz to the soil through a vibration wheel while rolling at a speed of 1m/s that provides a value of the Young´s modulus for every meter.

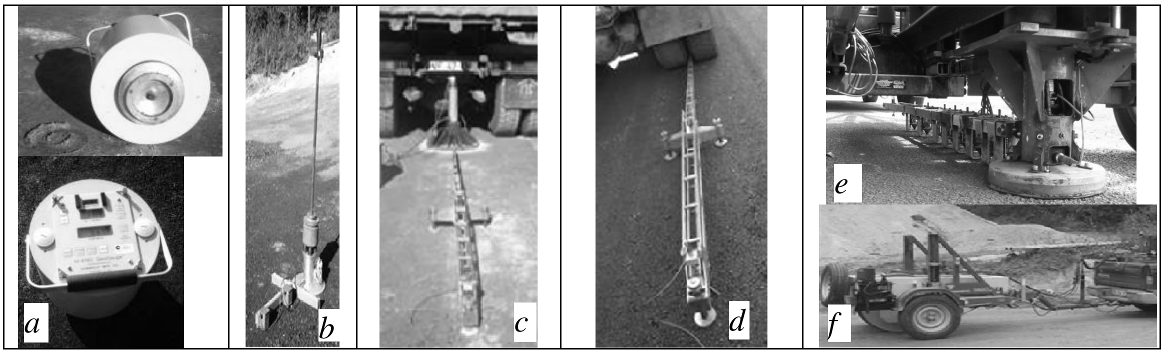

Figure 2: Field tests to assess the mechanical behavior – a) SSG; b) LFWD; c) SPLT; d) WLT; e) FWD; f) Portancemètre.

The assessment of mechanical performance of full-scale field trial was carried out periodically during 28 months. The settlement of the embankment was measured by superficial marks making readings with precision topography and by strain gauge rods. The behaviour of structural layers was done by strain gauges that measure the vertical (capping layer) and horizontal (bituminous layer) strains. The temperature of the bituminous layers was measured by thermocouples. More details of this instrumentation could be found at [2]. The stiffness assessment of pavement performance was done by FWD tests applying three different levels of loads: 20kN, 30kN and 47kN.

The assessment of the environmental performance was carried out throughout one year by means of two lysimeters, one located in the section built with ISAC and another in the section built with GRS. The GRS lysimeter is used as a referential in the environmental monitoring. The collected leachate in the section carried out with ISAC was mainly produced by feeding the lysimeter with water from a truck mounted water tank. This was only possible due to the high hydraulic conductivity of the ISAC, which made it possible to substantially reduce the time necessary for producing a significant amount of leachate. The remaining leachate was a result of rainwater. However, in the section carried out with GRS, its low hydraulic conductivity only permitted to feed the lysimeter by rainwater. During leaching, the leachate produced outside the lysimeter column is assumed to have poorly contributed to feeding the reception basin. More details could be found at [1,2].

3- RESULTS AND DISCUSSION

All the test results mentioned at this paper could be found at [2] and because lack of space here is only presented a few results that show the excellent mechanical and environmental behaviours of the ISAC.

According to the geotechnical current laboratory test (geometrical, physical and mechanical index test) ISAC is well graded and the fines are non-plastic, and meet the specifications of the Portuguese Roads Administration.

Figure 3a shows the result obtained by PTT from ISAC and GA. As can be seen the values found for the normalised Young´s Modulus for a void ratio of 0,35 (Enor) are too high, around 1GPa for a vertical stress of around 150kPa. This reveals the excellent mechanical behaviour (stiffness) of the ISAC. When compared with GA, a standard base layer construction material, the value of Enor for the ISAC is around four times higher than for the GA. From the PTCT tests was obtained a value of 6.98×10^{-4} for the characteristic axial permanent strain (difference between the accumulated strain after 2000 and 100 cycles). This value is too small which means that ISAC has little susceptibility to the build-up of permanent deformation. The PTCT results also show a value of 720MPa for the characteristic modulus, which means that, according to EN Standard 13289-7 (2004), the ISAC has excellent mechanical properties.

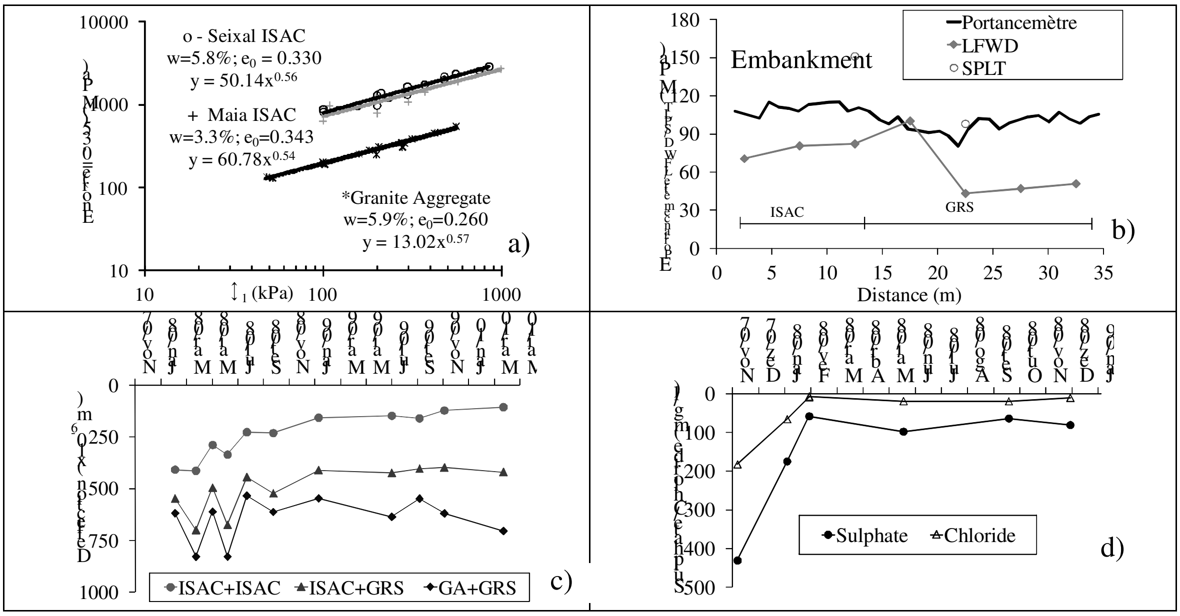

Figure 3: a) Laboratory Performance-based Test: PTT; Stiffness assessment b) during full-scale field trial construction; c) after full-scale field trial construction d) Evolution of leaching process of sulphates and chlorides at lysimeter located in the ISAC section

The better mechanical behaviour of ISAC than natural materials was confirmed during full-scale field trial construction, as can be seen from SPLT, Portancemètre and LFWD tests results presented at Figure 3b, were are observed that the Young´s modulus in ISAC section are higher than GRS section. From FWD test results it is observed that for the maximum deflections under 47kN in all the monitoring campaigns carried out in the field it is also remarkable the better performance of ISAC compared with the natural materials, as can be seen at Figure 3c.

Another important conclusion of this study, but not explored here because lack of space, was that this material has better mechanical properties when evaluated by laboratory performance-based tests than by index tests, corroborating previous findings [3] and stressing the priority to move to performance-based tests. This discussion could be found at [1, 2].

Relatively to the environmental properties of ISAC, obtained at laboratory and at field it was observed that all elements present lower values than the leaching limit values established in Decree-law N° 152/2002, for waste admissible in inert waste landfills, with the exception for nitrite in first collected leachate sample at lysimeter, which has a value higher (14 mg/l) than the one defined in the legislation (3mg/l). It is also observed that the contents of elements, which initially had a higher concentration, have rapidly decreased during the leaching process. For instance, sulfates decreased about 5 times (from 431 mg/l to 81 mg/l) and chlorides about 16 times (from 183 mg/l to 11 mg/l) as can be seen from Figure 3d. The complete leaching values can be consulted at **Erro! Fonte de referência não encontrada.**].

Hence, ISAC is, from a leachability point of view, and in accordance with the requirements established in the mentioned legislation, a waste admissible for inert waste landfills. The waste included in this class has been approved by the Portuguese Environment Agency for recycling in civil engineering works.

4- CONCLUSIONS

This study intends to describe the methodology used in a case study to promote the re-use of industrial byproducts, particularly processed steel slags aggregates (ISAC), as a substitute for natural aggregates or traditional materials used in transportation infrastructures and geotechnical works. This study follow the principles of sustainable development, once that allows the reduction of the quantities of waste that is disposed in landfill, allows the creation of a new and important national market and preserve natural raw materials.

The laboratory performance-based test results demonstrate that ISAC have better mechanical properties than standard base course materials. In addition to the laboratory study a full-scale trial has been built up and field tests carried out to evaluate mechanical and environmental performances. These test results validate the properties associated to the laboratory test results. Particularly, they demonstrate the better mechanical performance of ASIC when compared with natural material. Moreover, in which concerns the environmental aspects, they confirm that ISAC are an inert waste in terms of leacheability.

The technical data obtained in this study allowed that the processed steel slags, titled ISAC, were considered as a new construction material and, consequently, could be used in competition with natural aggregates for construction of transportation infrastructures and other geotechnical works.

REFERENCES

[1] Gomes Correia A., Roque A. J., Reis Ferreira S. M., Fortunato E.: Case Study to Promote the Use of Industrial Byproducts: The Relevance of Performance Tests. Journal of ASTM International (JAI), Paper ID JAI103705, 9, 2, p.18 (2012)

[2] Reis Ferreira, S.M. : Environmental and Mechanical Behvior of Granular Materials. Application to National Steel Slags. PhD Thesis, University of Minho (2010) (in Portuguese).

[3] Paute, J.L., Hornych, P. and Benaben, J.P. :Mechanical Behaviour of Unbound Granular Materials in Triaxial Cyclic Test. Bulletin de Liaison de Laboratories Central des Ponts et Chaussées, 190, 27-38 (1994) (in French).