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Valorisation of C&D waste as backfill material of geosynthetic reinforced structures – study of the long-term behaviour

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ABSTRACT: This paper presents an overview of the research project CDW_LongTerm - Valorisation of Construction and Demolition Wastes in geosynthetic reinforced structures - Prediction of long-term behaviour and summarizes its main conclusions. Mixed fine-grain recycled aggregates obtained from non-selected C&D waste, with low market acceptance for other applications such as pavement base layers and concrete production, were used in this study. Changes on the geotechnical and geoenvironmental behaviour of recycled C&D materials induced by real weather conditions and other agents (such as, compaction or wet-drying cycles), the durability and creep behaviour of the geosynthetics, the long-term behaviour of geosynthetic/C&D material interfaces and the long-term performance of a full-scale model have been studied. In general, the results show an acceptable long-term performance of the materials, of the recycled C&D materials/geosynthetic interfaces and of full-scale model.

1 INTRODUCTION

Waste generation and its efficient management is currently recognised as a key area of concern within the construction industry. In fact, construction and demolition (C&D) waste is one of the heaviest and most voluminous waste streams generated worldwide, accounting for over 35% of all waste produced in the European Union, EU (EC 2020). On the other hand, the responsible use of natural resources is among the fundamental pillars for the sustainable development demanded to modern societies. Since the construction sector is one of the main contributors to the consumption of natural resources, the use of alternative (recycled) materials in the construction and rehabilitation of civil infrastructure can make a significant contribution towards sustainable development.

In 2015, the European Commission (EC) presented the EU Circular Economy Action Plan to help European businesses and consumers to make the transition to a circular economy, where resources are used in a more sustainable way. C&D was among the priority sectors identified in this Circular Economy Package, because of the vast amounts produced across the EU and their high potential to be reused and recycled. More recently, a new EU Circular Economy Action Plan for a cleaner and more competitive Europe has been launched, in which Construction and Buildings (with special reference to C&D waste) is among the key priority value chains (EC 2020).

In recent decades, several studies on the use of recycled C&D wastes in a variety of civil engineering works have been reported in the literature with encouraging results (e.g. Arulrajah *et al.* 2013; Ferreira *et al.* 2021; Lu *et al.* 2021; Santos *et al.* 2014; Vieira *et al.*

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2016). However, most of these previous studies have investigated the short-term response of recycled C&D materials, and hence the knowledge about their long-term behaviour, as well as the overall long-term response of the structures where they are used is still limited.

In this context, the CDW_LongTerm research project focuses on the use of recycled C&D waste as an alternative backfill material for geosynthetic-reinforced structures (such as embankments and retaining walls), with special emphasis on the long-term response. As opposed to the majority of previous related studies, this research involves mixed recycled aggregates obtained from non-selected C&D wastes (the materials actually available on the Portuguese market). One of the main aims of this project is to demonstrate that geosynthetic-reinforced structures built with C&D materials are durable and fully capable of maintaining satisfactory performance throughout the design working life. This, in turn, will increase the confidence of owners, designers and constructors in the usage of recycled C&D wastes and promote the valorisation of waste materials, thus contributing towards the implementation of circular economy in the construction sector.

2 OVERVIEW OF THE RESEARCH PROJECT

The valorisation of recycled C&D waste as filling material, particularly in geosynthetic-reinforced structures, where it is possible to reach large heights and very steep slopes, represents significant economic and environmental benefits. On the one hand, the valorisation of C&D wastes contributes to achieve the recycling targets set out by the European Commission and prevents these wastes from ending up in landfills, and on the other hand, it avoids the environmental and economic costs related to the extraction of large volumes of borrow soils.

The research project CDW_LongTerm has dealt with the study of the long-term behaviour of geosynthetic-reinforced structures (GRS) constructed with recycled C&D materials. Thus, changes on the physical, mechanical and environmental properties of recycled C&D materials were studied, the durability and creep behaviour of geosynthetics after exposure to recycled C&D materials and the long-term behaviour of the interfaces between the geosynthetics and the recycled materials were assessed, and the overall performance of a full-scale instrumented geosynthetic-reinforced structure, as well as its numerical model were also carried out.

The long-term behaviour of geosynthetics when inserted into recycled C&D materials was investigated by exposing the geosynthetics to the recycled wastes under real environmental conditions (Figure 1a) and under artificial conditions (wet-dry cycling tests, Figure 1b). After

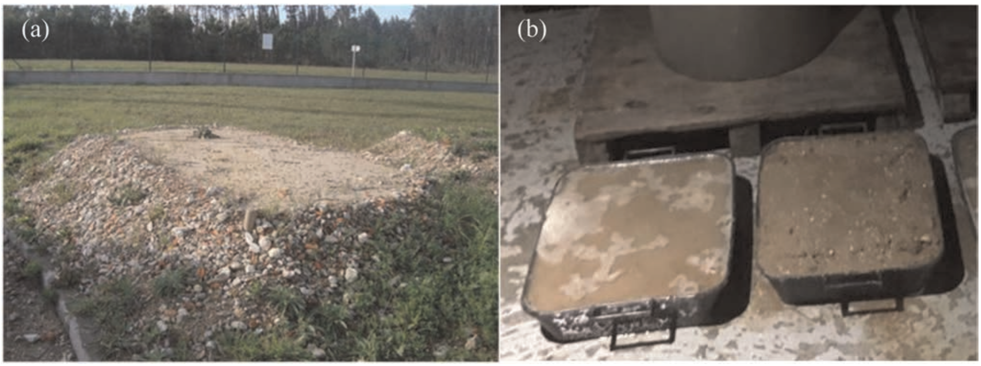

Figure 1. Exposure of the geosynthetics to the recycled C& D wastes: (a) under real environmental conditions; (b) wetting-drying cycles.

exposure the geosynthetic samples were subjected to tensile and creep tests to characterise the effects on the short-term and long-term behaviour, respectively. Scanning Electron Microscope (SEM) analyses were carried out on intact and exhumed samples.

An extensive laboratory test programme has been conducted involving conventional and multistage direct shear and pullout tests to investigate the long-term response of recycled C&D waste-geosynthetic interfaces.

The direct shear tests were performed using a large-scale direct shear test apparatus (Vieira el al. 2013). Apart from conventional direct shear tests, two types of multistage tests were also carried out to simulate the effects of creep (Figure 2a) and stress relaxation (Figure 2b) at the interfaces (i.e. time-dependent behaviour).

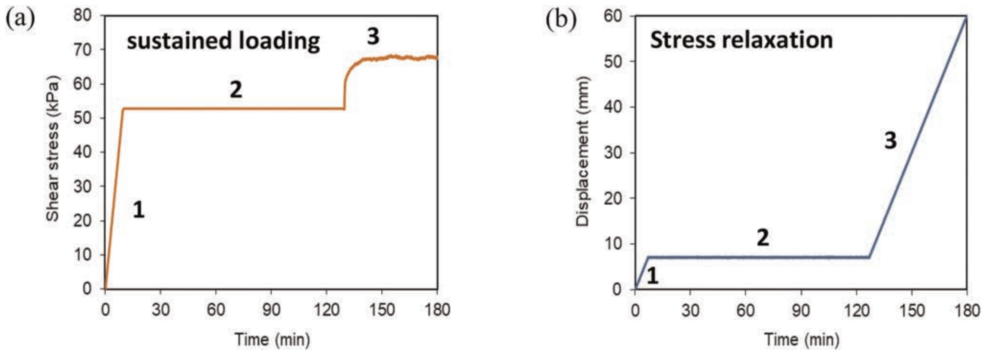

Figure 2. Different setups of the multistage direct shear tests: (a) sustained loading; (b) stress relaxation.

Sustained load pullout tests were also carried out on recycled C&D material/geogrid interfaces on a large scale apparatus (dimensions in plan of 1.53m x 1.0m and 0.8 m high). The test procedure is similar to the one schematically shown in Figure 2(a), although much longer: the pullout force was applied under load controlled model until a predefined value (equal to 40% or 70% of the pullout resistance under monotonic loading), in a second stage the pullout force was held constant for a predefined time slot (30 or 120 minutes), during which the geogrid pullout displacement was monitored and in the last stage, the test proceeded until the failure of the interface.

A full-scale experimental embankment with two geosynthetic-reinforced slopes has been constructed using recycled C&D materials as backfill material (Figure 3a). The full-scale

Figure 3. Full-scale instrumented geosynthetic-reinforced structure: (a) during construction; (b) readings on the inclinometers; (c) pressure cells readings.

instrumented model consists of a 3.1 m high, 10.4 m long and 3.0 m wide geosynthetic-reinforced embankment composed of two wrapped-face slopes with a face inclination of 63.4° with the horizontal (batter of 1H:2V). Fine-grained recycled C&D materials were sourced from a Portuguese recycling plant and used as backfill. The southern slope was reinforced with a uniaxial woven geogrid, GGR3 (Figure 5c) and a uniaxial geocomposite reinforcement, GCR2 (Figure 5e) was used to reinforce the northern slope. The geosynthetic reinforced structure was built in a reinforced masonry block container with a reinforced concrete foundation.

To monitor the performance of the geosynthetic-reinforced structure. geotechnical instrumentation was installed during its construction. Specifically, the instrumentation system included: 4 inclinometer casings, 4 magnetic extensometers (with a total of 20 magnetic targets), 2 soil settlement gauges, 10 earth pressure cells, 35 electrical strain gauges attached to the geogrid, 12 mechanical extensometers (tell-tales) attached to the geocomposite, 4 settlement plates and 50 survey points at the slope faces and on the side walls. Figures 3(b) and 3(c) illustrates the collection of some readings during a monitoring campaign. In order to assess the long-term performance of the reinforced structure, the monitoring process is expected to remain for several years beyond the project end. Additional information regarding the full-scale model, instrumentation and monitoring can be found in Vieira *et al.* (2023).

The numerical modelling of the behaviour of the full-scale geosynthetic-reinforced structure was also performed using the three-dimensional explicit finite-difference software FLAC 3D (*Itasca Consulting Group, Inc.*). Five 0.6 m thick layers of recycled C&D material were simulated with the geosynthetic reinforcement layers placed at the appropriate locations along the height of the lateral slopes. The slopes were modelled with wrap-around facing, resembling actual field conditions.

3 MATERIALS

The fine grained recycled C&D materials used in the current research consisted of the finer fraction (0–10 mm) obtained during the recycling process of C&D wastes. The materials used in the project were obtained from three different batches (i.e. collected from the recycling plant at different times, but after being subjected to the same recycling process) and consisted mainly of soil, unbound and hydraulically bound aggregates, concrete and mortar products. Figure 4 illustrates the type of recycled material used in this study.

Figure 4. Visual appearance of the recycled materials used in the study.

Figure 5 presents the photographic views of the geosynthetics tested in CDW_LongTerm project. It should be mentioned that not all the geosynthetics were subjected to the same test or exposure conditions.

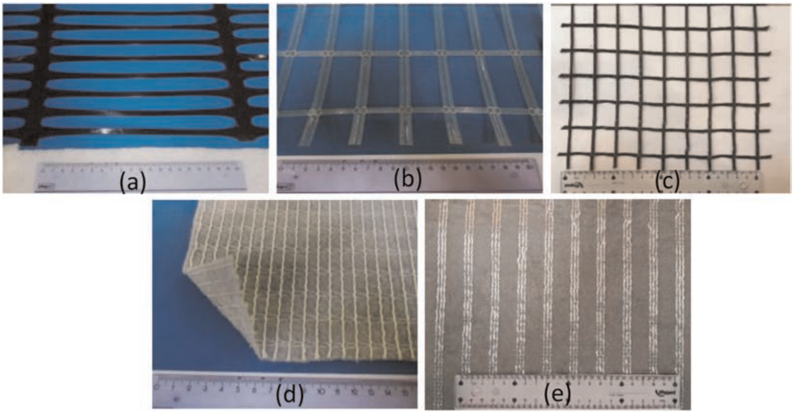

Figure 5. Geosynthetics used in the study (ruler in centimetres): (a) uniaxial high-density polyethylene geogrid (GGR1); (b) polyester welded geogrid (GGR2); (c) polyester woven geogrid (GGR3); (d) geocomposite reinforcement 1 (GCR1); (e) geocomposite reinforcement 2 (GCR2).

4 RESULTS AND DISCUSSION

Figure 6 presents the effects on the tensile strength of geosynthetics GGR1, GGR2 and GCR1 (Figure 6a) and on their tensile stiffness for 2% of strain (Figure 6b) of different exposure conditions (specimens immediately exhumed, exposure to recycled C&D material, exposure to soil).

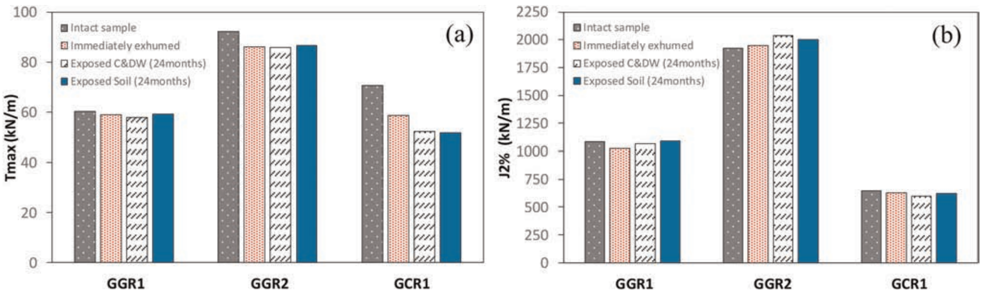

Figure 6. Effects of exposure of geosynthetics to a recycled C&D waste and other conditions: (a) on maximum tensile strength; (b) tensile stiffness at 2% strain.

From Figure 6 it can be concluded that the effects of exposure to recycled C&D material and to soil are similar and, with the exception of geotextile GCR1, in general the tensile strength after immediate exhumation is close to that obtained after exposure for 24 months. The loss of tensile strength of GCR1 is most likely due to the less effective binding of the PET yarns to the nonwoven geotextile, caused by handling during installation, rather than damage induced by the compaction or exposure to the filling materials.

Figure 7 shows the creep behaviour of intact specimens (as provided by the manufacturer) of the geocomposite GCR1 (Figure 5d) and of specimens that were previously exposed to the recycled C&D waste for a period of 24 months.

When subjected to the same tensile force, the intact specimens exhibited higher tensile strength properties than the exhumed specimens However, the estimate of the long-term available strength, considering the extrapolation of the creep rupture curves, for the specimens that were previously exposed to recycled C&D waste will be more optimistic when compared to the intact specimens (higher retained strength), (Figure 7). This finding suggests that the conventional approach (use of intact specimens) to estimate the long-term tensile strength of geosynthetics through creep rupture tests is a conservative procedure (Ferreira *et al.* 2022).

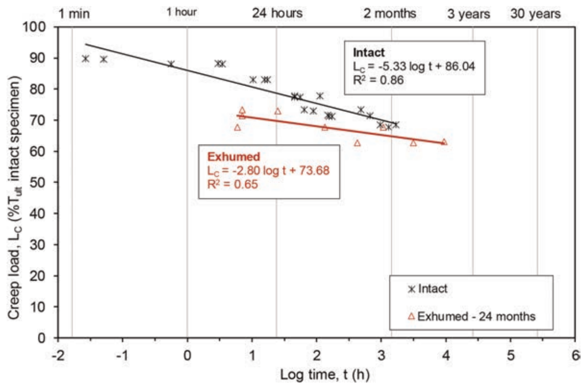

Figure 7. Applied creep loads *vs* time to rupture and associated rupture curves (modified from Ferreira *et al.* 2022).

Figure 8 compares the results of conventional and stress relaxation direct shear tests (Figure 2b) to characterize recycled C&D material/geotextile GCR2 interface. As shown in Figure 8, and for the test conditions analysed in this project, the effect of stress relaxation on the interface behaviour was almost negligible, implying that the conventional large-scale direct shear tests can be considered suitable to characterise the long-term interface strength properties under direct shear mode (Ferreira *et al.* 2021).

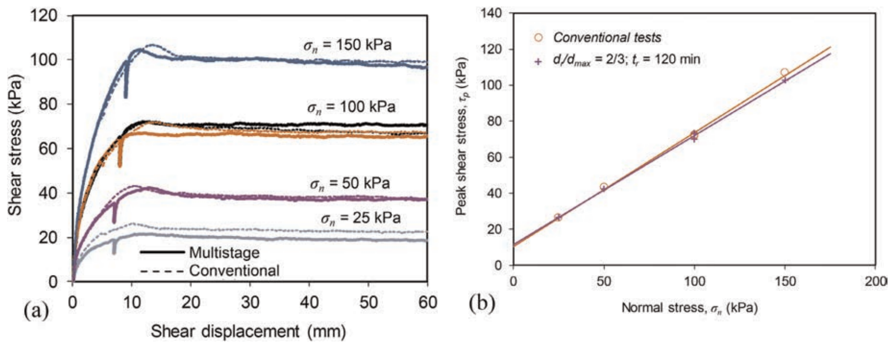

Figure 8. Results of conventional and multistage (stress relaxation) direct shear tests to characterize recycled C&D material/GCR2 interface (adapted from Ferreira *et al.* 2021): (a) shear stress-shear displacement curves; (b) interface failure envelopes.

5 MAIN CONCLUSIONS

The main goal of the research project CDW_LongTerm was to demonstrate the good long-term performance of geosynthetic-reinforced structures constructed with recycled C&D wastes, reducing the barriers on the use of alternative materials and giving an important contribution to the reduction of human carbon footprint. Based on the results obtained in the extensive laboratory programme and the satisfactory behaviour of the full-scale geosynthetic-reinforced structure (even though it has been subjected to very adverse weather conditions - at least one extremely rainy winter) it is considered that these objectives have been achieved.

Among the main conclusions of this study, the following must be highlighted:

- Laboratory leaching tests carried out on all the recycled C&D materials have shown that only the sulphates exceeds the maximum value established by the European legislation for inert landfill. All the other pollutants are significantly below the limits.
- In general, the changes induced by the compaction procedures, weather conditions and adverse artificial conditions on the physical and mechanical behaviour of the recycled C&D materials are not significant.
- The effects of stress relaxation and sustained loading on interfaces direct shear strength and pullout resistance can be considered almost negligible, which suggests that good performance can be expected in the long term.

ACKNOWLEDGEMENTS

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