

Wetting-Drying Cycles on Geosynthetics Embedded in Construction and Demolition Waste (C&DW) - Effects on Tensile Behaviour

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Abstract. Construction activities account for up to 40% of global raw material extraction and generate approximately 35% of the total solid waste produced worldwide. Reducing the exploitation of non-renewable resources and increasing waste valorisation and reuse are therefore crucial for achieving a more sustainable society. Geotechnical design, as an integral part of civil engineering projects, can significantly contribute to the sustainability of the built environment. Recycled C&DW have been increasingly considered as alternative materials for civil engineering applications such as unbound pavement layers and structural embankments, where geosynthetics are frequently used. While the durability of geosynthetics is an important concern when conventional materials are applied, it becomes even more critical when alternative materials are employed. This paper presents a laboratory study conducted to evaluate the effect of wetting–drying (W–D) cycles on the tensile behaviour of two geosynthetics embedded in recycled aggregates coming from C&DW. These cycles intend to simulate climatic variations over the service life of geotechnical structures. Overall, the results demonstrate that cyclic wetting-drying exposure does not significantly impair the tensile performance of the geosynthetics.

1 Introduction

Minimizing the consumption of non-renewable natural resources for the production of construction materials is considered one of the key aspects to achieve sustainability in the construction sector. The recovery of Construction and Demolition Waste (C&DW) as aggregate is an efficient way to achieve this purpose. Adopting and implementing this principle is particularly relevant for an industry that consumes more raw materials than any other economic activity and produces huge amounts of waste [1].

C&DW are wastes derived from construction, reconstruction, cleaning of the work site and earthworks, demolition and collapse of buildings, maintenance and rehabilitation of existing constructions. Recycled C&DW have been increasingly used as recycled aggregates in pavement sub-bases and other road construction applications. Furthermore, unpaved roads constructed with recycled C&DW materials can be effectively reinforced with geosynthetics, where they may also have separation and drainage functions. However, one of the main concerns of using geosynthetics in ground and environmental applications is their durability. Thus, the degradation over time of their properties is an important issue to be considered. This aspect is particularly relevant when alternative materials are being used.

Geotechnical infrastructures such as pavement subgrades and sub-base layers generally have an

expected lifespan ranging from 50 to 100 years. They should be designed to undergo cyclic weathering solicitations as temperature and moisture content variations. The changes in the physical, mechanical and hydraulic properties of geosynthetics are among the factors that may influence the performance of the structures or infrastructures where they are used.

The available long-term tensile strength of a geosynthetic [2,3], T_{al} , or the design strength for the ultimate limit state [4], can be estimated as (Equation 1):

$$T_{al} = \frac{T_{ult}}{RF_{ID} \times RF_{CR} \times RF_D} \quad (1)$$

where T_{ult} is the ultimate tensile strength (per unit width) of the geosynthetic, RF_{ID} is the installation damage reduction factor, RF_{CR} is the creep reduction factor and RF_D is the durability reduction factor (that accounts for the strength loss caused by chemical and biological degradation of the polymers used in the geosynthetic). Instead of the durability reduction factor, RF_D , the British Standard BS 8006 [4] considers two reduction factors: a reduction factor for weathering, RF_w , and a reduction factor for chemical/environmental effects, RF_{CH} .

In this context, experimental studies are essential to assess the effects of climatic conditions on the tensile behaviour of geosynthetics and to support the definition of appropriate reduction factors. The present work contributes to this objective by evaluating the influence of wetting–drying cycles on the tensile performance of geosynthetics embedded in recycled C&DW.

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This paper presents and discusses the effects of 52 wetting-drying (W-D) cycles, carried out under controlled conditions, on the short-term tensile behaviour of two geosynthetics (a high-strength geotextile and a geogrid) embedded in a fine-grain recycled aggregate. The constituents and the leaching behaviour of the recycled aggregate are also presented.

The present study is part of a broader research project focused on the long-term behaviour of geosynthetics used in geotechnical structures built with recycled C&DW as filling material.

2 Materials and methods

The geosynthetics used in this study were a uniaxial geogrid manufactured of high modulus polyester (PET) fibres (Fig. 1a), with aperture dimensions of 25 mm × 25 mm and a polypropylene continuous-filament needle-punched nonwoven geotextile reinforced with high-strength polyester yarns (Fig. 1b).

The filling material used in this study was a fine-grain recycled C&DW coming mainly from maintenance works or demolitions of small buildings and cleaning of lands with illegal deposition of C&DW (Fig. 2a). The particle size determined by sieving and sedimentation of the recycled C&DW is represented in Fig 2b. This recycled C&DW was provided by a Portuguese recycling plant.

The constituents of the recycled aggregates, evaluated by hand visual sorting of particles, are presented in Fig. 3. The contents of concrete, concrete products, mortar, concrete masonry units, Rc, unbound aggregate, natural stone, hydraulically bound aggregate, Ru, clay masonry units, calcium silicate masonry units, aerated non-floating concrete, Rb, bituminous materials, Ra, glass, Rg, soils, Rs, and other materials, X, were assessed.

It is important to point out that the standard EN 933-11 [5] refers to the constituents of coarse recycled aggregates which means that only the mass comprised between the sieves 63 mm and 4 mm is analysed. The classification of the particles with dimensions lower than 4 mm by visual sorting is considered to be humanly impracticable. Fig. 3a shows the constituents of the analysed fraction (this means particles larger than 4 mm), while in Fig. 3b the percentages refer to the whole material. In fact, 82.6% of the material consists of particles smaller than 4 mm, making it impossible to classify its constituents. The floating particles content, FL, estimated during the classification test was 0.1 cm³/kg of dry mass and 7.6 cm³/kg of dry mass for coarse and fine recycled aggregates, respectively.

Table 1 shows the results of the laboratory leaching test carried out on the recycled aggregate, as well as the acceptance criteria for leached maximum concentration for inert landfills stipulated by the European Council Decision 2003/33/EC [7].

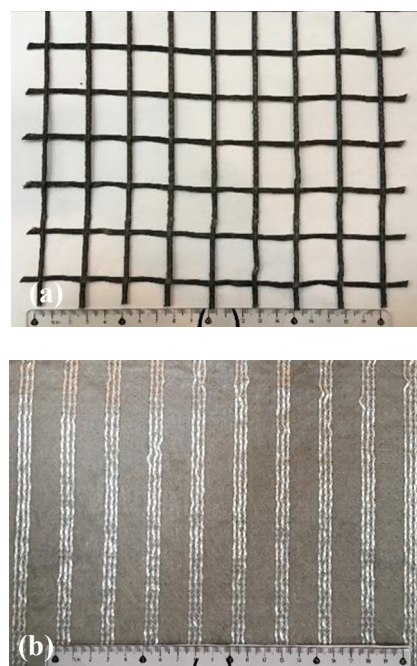


Fig. 1. Geosynthetics used in the study (ruler in centimetres): (a) uniaxial geogrid; (b) high-strength geotextile.

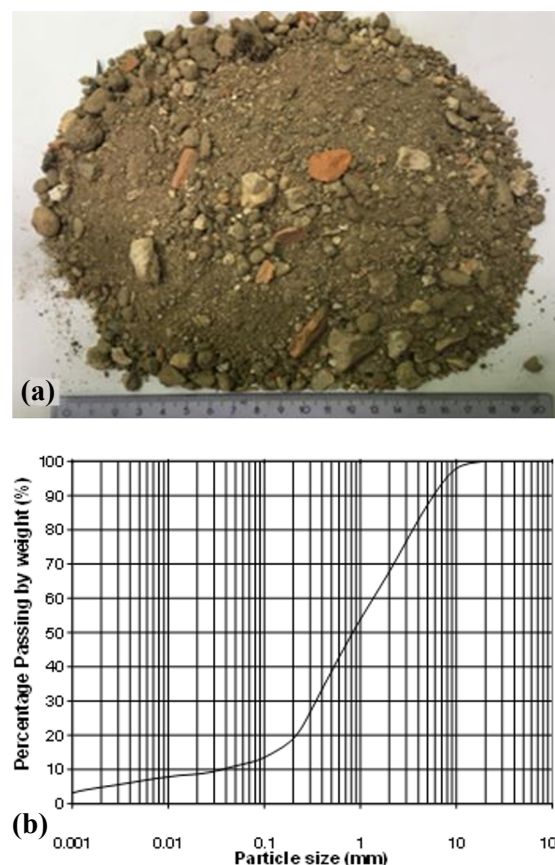


Fig. 2. Fine recycled C&DW: (a) visual aspect (ruler in centimetres); (b) particle size distribution.

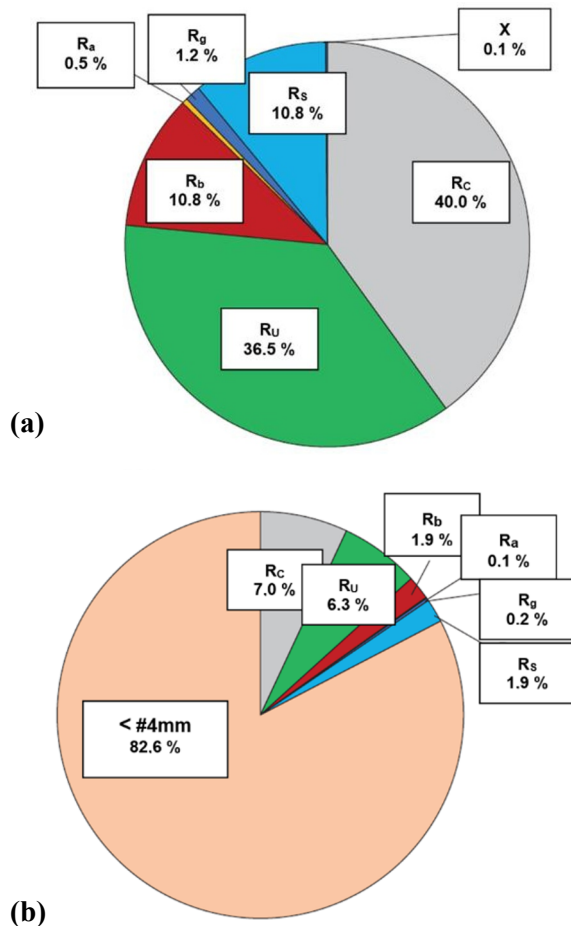


Fig. 3. Constituents of fine recycled C&DW (adapted from [6]): (a) fraction larger than 4 mm; (b) total sample.

When a recycled aggregate fulfils the requirements set for inert landfills, it can be considered as an inert material. As shown in Table 1 only the content of sulphate, SO_4 , in the eluate of the fine recycled aggregate exceeded the threshold value. However, the above mentioned European Council Decision states that “if the waste does not meet these values for sulphate, it may still be considered as complying with the acceptance criteria if the leaching does not exceed 6000 mg/kg at $\text{L/S} = 10 \text{ l/kg} \dots$ ”, which means that the sulphate content found in the eluate is not of real concern. High concentrations of sulphate in non-selected recycled aggregates have been described by other authors [8,9]. The physical, mechanical, chemical and environmental characterization of the recycled C&DW used in this study is reported in detail in [6].

The containers used in the W-D cycles were filled with three layers of the fine-grained C&DW, interspersed with geosynthetics samples. During each W-D cycle, the containers filled with recycled C&DW and geosynthetics samples were completely immersed in water and placed in a humid chamber (temperature, $T = 20 \text{ }^\circ\text{C}$ and relative humidity, RH, close to 100%), for 2 days. After this period, the containers were moved out of the humid chamber and were placed in an oven, for 5 days, at a temperature of $60 \text{ }^\circ\text{C}$ (Fig. 4). These procedures were repeated for 52 cycles, corresponding to approximately 1 year. At the end of the 52 cycles the geosynthetics samples were carefully removed from the

containers and were stored in an atmosphere-controlled room until testing.

It should be noted that the conditions imposed are not similar to the weather conditions to which geosynthetics are generally exposed in real-world applications. However, the W-D cycles were designed to simulate long-term exposure by accelerating natural weathering processes. While natural cycles depend on stochastic rainfall events, the laboratory procedure ensures full saturation and drying, simulating the ‘worst-case scenario’ for flooding (e.g. periods of heavy rain or a rise in the water level)). A temperature of $60 \text{ }^\circ\text{C}$ was selected to accelerate moisture loss and potential chemical interactions (leaching/oxidation) between the geosynthetic and the C&DW, without reaching the thermal degradation threshold of the polymers, thereby providing a conservative yet realistic representation of durability under real-world conditions.

The damage induced by W-D cycles on the geosynthetics was evaluated qualitatively by visual inspection and quantitatively by monitoring the changes that occurred in their tensile properties. The tensile tests were carried out on intact specimens (as supplied by the manufacturers) and on specimens subjected to 52 W-D cycles. The tensile strength tests were performed in a Universal Testing Machine (Fig. 5) on five specimens for each condition (intact or exposed), following the European Standard EN ISO 10319 [10] with strain rate of $20\%/min$.

Table 1. Results of laboratory leaching tests of the recycled aggregates and corresponding acceptance criteria [6].

Parameter (mg/kg dry matter)	C&DW	Acceptance criteria – Inert landfill [7]
Arsenic, As	0.03	0.5
Lead, Pb	< 0.3	0.5
Cadmium, Cd	< 0.04	0.04
Chromium, Cr	< 0.5	0.5
Copper, Cu	< 0.25	2
Nickel, Ni	< 0.3	0.4
Mercury, Hg	< 0.01	0.01
Zinc, Zn	0.52	4
Barium, Ba	0.16	20
Molybdenum, Mo	0.03	0.5
Antimony, Sb	< 0.01	0.06
Selenium, Se	0.02	0.1
Chloride, Cl	56	800
Fluoride, F	< 2	10
Sulphate, SO_4	1200	1000
Phenol index	< 0.05	1
Dissolved Organic Carbon, DOC	< 200	500
Total Dissolved Solids, TDS	3500	4000
pH	8.6	-

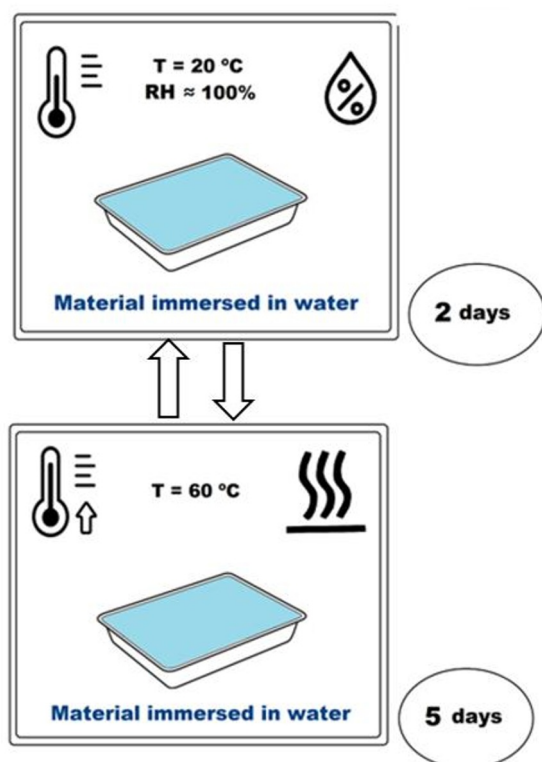


Fig. 4. Schematic representation of the wetting–drying (W–D) cycles.



Fig. 5. Apparatus of tensile strength tests of the geosynthetics.

3 Results and discussion

3.1 Visual inspection of the exposed specimens and recycled C&DW degradation

The W-D cycles induced practically no visible damage to the geosynthetics structure, only some minor abrasion on the contact surfaces between the geosynthetics and the recycled material (Fig. 6).

The evolution of the particle size distribution (PSD) of the recycled C&DW material after wetting-drying (W-D) cycles is illustrated in Fig. 7. A distinct upward and leftward shift in the gradation curve is observed

following the W-D conditioning, signalling a process of physical particle degradation. The percentage of fines (particles $< 0.075\text{ mm}$) increased from approximately 12% to 18%, while the median particle diameter (D_{50}) decreased from roughly 1.0 mm to 0.6 mm. This behaviour demonstrates that the coarser fractions of recycled aggregate are susceptible to fragmentation and disintegration when subjected to cyclic moisture variations, typical of materials featuring attached mortar and porous ceramic elements.

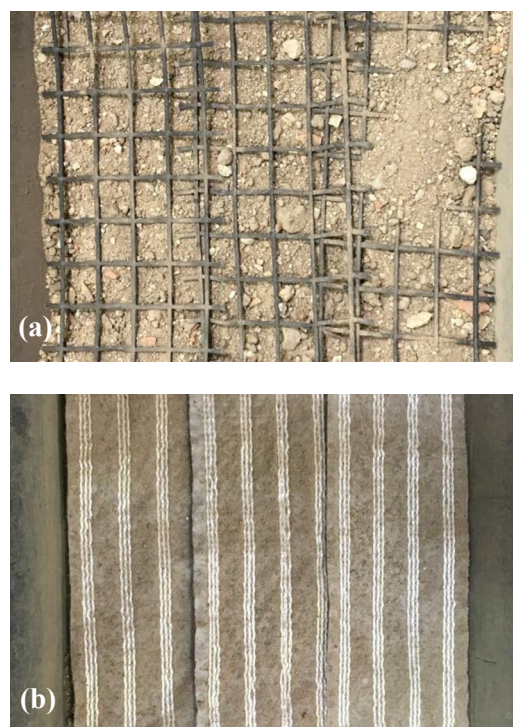


Fig. 6. Visual inspection of the exposed specimens after the W-D cycles: (a) uniaxial geogrid; (b) high-strength geotextile.

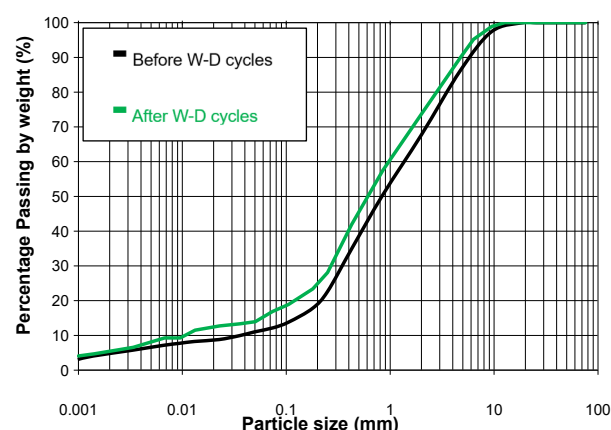


Fig. 7. Particle size distribution of recycled C&DW before and after the Wet-Dry cycles.

3.2 Uniaxial Geogrid

Table 2 summarises the values of maximum tensile strength ($T_{\max}$), strain for $T_{\max}$ ($\epsilon_{T_{\max}}$), secant stiffness modulus at strain of 2% ($J_{2\%}$) and for $T_{\max}$ ($J_{T_{\max}}$) for intact samples and samples exposed to 52 W-D cycles. The mean values of these parameters and the 95%

confidence intervals assuming a Student's t-distribution were also tabulated.

Table 2. Summary of results of tensile tests carried out on the uniaxial geogrid.

		$T_{\max}$ (kN/m)	$\epsilon_{T_{\max}}$ (%)	$J_{2\%}$ (kN/m)	$J_{T_{\max}}$ (kN/m)
Intact specimens	Mean value	30.9	9.3	523	333
	Confidence interval of 95%	30.9 ± 2.3	9.3 ± 0.9	523 ± 62	333 ± 41
Specimens subjects to W-D cycles	Mean value	28.9	7.7	544	376
	Confidence interval of 95%	28.9 ± 6.1	7.7 ± 0.7	544 ± 59	376 ± 49

The mean value of the tensile strength obtained for intact specimens is slightly lower than the value provided by the manufacturer (38 kN/m). There is a clear reduction in ductility as after the weathering cycles, the geogrid reaches its maximum strength significantly earlier than the intact material. It should also be noted that the maximum tensile force is achieved for a value of strain of 9.3% and a secant stiffness modulus around 523 kN/m at strain of 2%. The comparison of the results presented in Table 2 points out that the loss of strength caused by the exposure to W-D cycles is very small (loss of 6.5 %).

Analysing the results presented in Table 2 one can conclude that the mean value of the tensile strength ($T_{\max}$) of the specimens after W-D cycles is inside the confidence interval of this parameter for intact specimens. A similar conclusion can be drawn for the secant stiffness modulus at 2% strain ($J_{2\%}$). However, a different trend is observed for the remaining parameters: the tensile strain at maximum force ($\epsilon_{T_{\max}}$) decreased significantly, while the secant stiffness modulus at maximum force ($J_{T_{\max}}$) increased, with values falling outside the confidence intervals of the intact samples.

Fig. 8 compares the tensile behaviour of the geogrid (mean curves) of intact specimens and specimens submitted to W-D cycles.

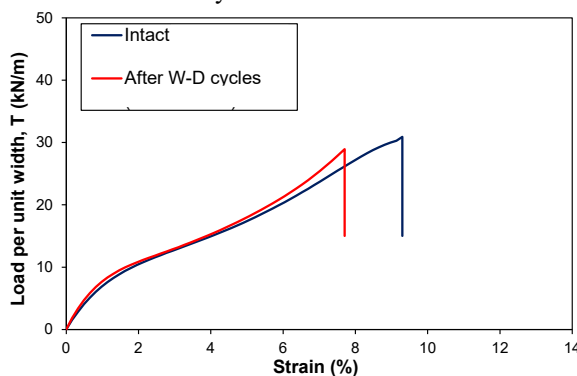


Fig. 8. Comparison of mean load-strain curves of intact and exhumed after the W-D cycles specimens of geogrid.

The shape of curves is quite similar but the coordinates at failure were shifted. The geogrid tensile stiffness for very small strains (initial stiffness) and at $\epsilon_{T_{\max}}$ ($J_{T_{\max}}$) increase after the W-D cycles. This stiffness

increase is consistent with findings from other studies, notably [11, 12] who observed similar shifts in the tensile response of geosynthetics following exposure to degradative environments with fine soils and recycled aggregates.

3.3 High-strength geotextile

The values of maximum tensile strength ($T_{\max}$), strain for $T_{\max}$ ($\epsilon_{T_{\max}}$), secant stiffness modulus at strain of 2% ($J_{2\%}$) and at $\epsilon_{T_{\max}}$ ($J_{T_{\max}}$) for intact and exhumed specimens are summarized in Table 3. Table 3 also presents the mean values for these parameters, accompanied by their respective 95% confidence intervals, calculated based on a Student's t-distribution.

The tensile strength reached in laboratory tests of intact specimens exceeded the mean value provided by the manufacturer (42 kN/m). It would be expected that the variability of the results for exposed samples would be greater than that of intact samples, due to the different mechanisms that might contribute to the high-strength geotextile damage however, tensile tests carried out with intact samples have shown greater variability. This variability is usual and it might be attributed to the production process.

There is a slight decrease in the mean value (approximately 5.4%) of the maximum tensile strength ($T_{\max}$). However, the value after the W-D cycles remains within the confidence interval of the intact samples, suggesting that the maximum strength was not compromised by the W-D cycles.

Table 3. Summary of results of tensile tests carried out on the high-strength geotextile.

		$T_{\max}$ (kN/m)	$\epsilon_{T_{\max}}$ (%)	$J_{2\%}$ (kN/m)	$J_{T_{\max}}$ (kN/m)
Intact specimens	Mean value	46.4	11.3	698	411
	Confidence interval of 95%	46.4 ± 9.1	11.3 ± 0.4	698 ± 56	411 ± 50
Specimens subjects to W-D cycles	Mean value	43.9	10.0	693	439
	Confidence interval of 95%	43.9 ± 7.5	10.0 ± 0.6	693 ± 47	439 ± 61

The secant stiffness modulus of 2% remained almost constant, moving from 698 kN/m to 693 kN/m. This shows that the initial stiffness of the high-strength geotextile was not significantly affected by the W-D cycles. The mean value of the strain at failure after W-D cycles (10.0%) falls outside the confidence interval of the same parameter for intact specimens (10.9% to 11.7%), which represents a decrease in the material's ductility.

Fig. 9 compares the average curves of the intact specimens and of the specimens exposed to W-D cycles. The tensile stiffness of the high-strength geotextile for very small deformations (initial stiffness) did not change significantly, while an increase in the secant stiffness modulus at $T_{\max}$ is noted for the samples exposed to W-D cycles ($J_{T_{\max}}$). The reduction in $\epsilon_{T_{\max}}$ and the increase

in J_{Tmax} indicate that the W-D cycles induced a higher rigidity at failure.

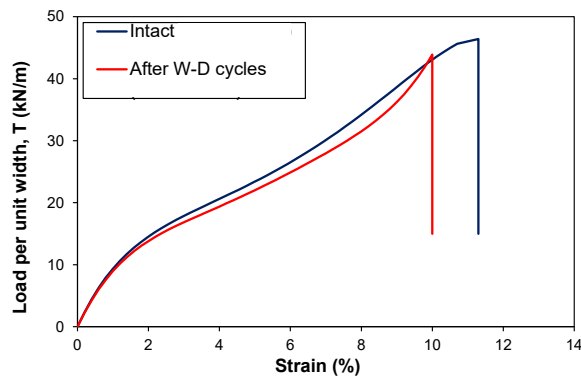


Fig. 9. Comparison of mean load-strain curves of intact and exhumed after the W-D cycles specimens of high-strength geotextile.

3.4 Reduction Factors

The damage on geosynthetics used as reinforcement is currently quantified by the retained values of relevant parameters, such as, the tensile strength, the strain at maximum load or the secant stiffness modulus. The retained value of the parameter X can be defined as the ratio between the mean value of the parameter X for specimens exposed to W-D cycles and the corresponding mean value for intact specimens (Equation 2).

$$R_X = \frac{\bar{X}_{After\ W-D\ cycles}}{\bar{X}_{Intact}} \quad (2)$$

The mean values of the retained tensile strength, R_T , retained peak strain, R_E , and retained secant modulus at 2% of strain, $R_{J2\%}$ are presented in Table 4.

Table 4. Mean values of R_T , R_E and $R_{J2\%}$ for both geosynthetics after W-D cycles.

Uniaxial Geogrid			High-strength geotextile		
R_T (%)	R_E (%)	$R_{J2\%}$ (%)	R_T (%)	R_E (%)	$R_{J2\%}$ (%)
93.5	82.8	104.0	94.6	88.5	99.3

Both geosynthetics showed a similar and relatively low reduction in tensile strength. The high-strength geotextile exhibited a slightly higher retained tensile strength (94.6%) than the uniaxial geogrid (93.5%). This indicates that the exposure of this geosynthetics to a fine-grain recycled C&D aggregate under cyclic weathering conditions did not induce significant degradation. However, the uniaxial geogrid was notably more susceptible to loss of ductility, as its retained peak strain (R_E) dropped to 82.8%, compared to 88.5% for the high-strength geotextile. Furthermore, while retained secant modulus at 2% of strain ($R_{J2\%}$) for the high-strength geotextile remained practically unaffected (99.3%), the uniaxial geogrid showed an increase in stiffness (104.0%).

4 Conclusions

This study investigated the effects of cyclic wetting–drying (W–D) conditions on the tensile behaviour of a uniaxial PET geogrid and a high-strength geotextile embedded in a fine recycled aggregates coming from construction and demolition waste (C&DW). Based on the experimental results obtained after 52 W–D cycles, the following conclusions can be drawn:

1. The exposure of both geosynthetics to fine recycled aggregate under cyclic wetting–drying conditions resulted in only minor changes in tensile behaviour. The reduction in maximum tensile strength was limited to approximately 6–6.5%, which is small when compared with the variability inherent to tensile testing.
2. The strain at maximum tensile load slightly decreased after W–D exposure for both materials, while the secant stiffness modulus at low strains and at peak load was maintained or slightly increased. This indicates that cyclic environmental exposure did not adversely affect the stiffness performance of the geosynthetics and may even lead to a modest stiffening effect.
3. The retained values of tensile strength, strain, and stiffness demonstrate that the combined mechanical, chemical, and environmental actions associated with the applied W–D cycles did not induce relevant degradation of the studied geosynthetics. This behaviour was observed despite the contact with a fine recycled aggregate presenting sulphate contents close to regulatory thresholds.

Overall, the results support the technical feasibility and durability of using geosynthetics in geotechnical infrastructures such as pavement subgrades and sub-base layers involving recycled C&DW, contributing to more sustainable construction practices. Nevertheless, further research is recommended to assess longer exposure periods.

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