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Laboratory evaluation of the mechanical damage induced to geotextiles by incinerator bottom ash

Évaluation en laboratoire des dommages mécaniques induits sur les géotextiles par les mâchefers d'incinérateur

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ABSTRACT: The design of solutions involving waste valorisation is a key step towards sustainable development. The generated waste should be recovered and introduced into economic activities, moving away from the usual disposal practices with negative environmental impacts (e.g. landfilling). The incineration process of municipal solid waste leads to the generation of a residue known as incinerator bottom ash. This residue shown, among other alternatives, the potential to be used as recycled aggregate in geotechnical structures, where it may be in contact with geosynthetics. Similar to other aggregates commonly used in these type of structures, incinerator bottom ash may induce mechanical damage on the geosynthetics during the installation process (e.g. during the placement and compaction operations). In this work, geotextiles with different structures (woven and nonwoven), and masses per unit area, were submitted to laboratory mechanical damage under repeated loading tests, which are often used to simulate the damaging actions occurred during the installation process. Besides incinerator bottom ash, a standard aggregate (*corundum*) and a natural aggregate (*tout-venant*) were also used in the mechanical damage tests for comparison purposes. Tensile and puncture tests were performed in order to monitor the changes occurred in the mechanical properties of the geotextiles during the mechanical damage tests. The results, among other findings, revealed that there are good perspectives for the use of incinerator bottom ash as recycled aggregate in geotechnical engineering applications, where it may be in contact with geosynthetics.

RÉSUMÉ: La conception de solutions de valorisation des déchets est une étape fondamentale vers le développement durable. Les déchets générés devraient être valorisés et introduits dans les activités économiques, en évitant les pratiques d'élimination habituelles avec des impacts environnementaux négatifs (par exemple, la mise en décharge). Le processus d'incinération des déchets solides municipaux conduit à la formation d'un résidu appelé mâchefer d'incinérateur. Ce résidu a montré, entre autres alternatives, le potentiel d'être utilisé comme agrégat recyclé dans les structures géotechniques, où il peut être en contact avec des géosynthétiques. Comme avec d'autres agrégats normalement utilisés dans ce type de structures, les mâchefers d'incinérateur peuvent induire des dommages mécaniques aux géosynthétiques pendant le processus d'installation (par exemple, pendant les opérations de mise em place et de compactage). Dans ce travail, des géotextiles avec différent structures (tissés et non tissés), et des masses par unité de surface, ont été soumis à des tests en laboratoire pour évaluer l'endommagement mécanique sous charge répétée, qui sont normalement utilisés pour simuler les actions de dommages qui se produisent pendant le processus d'installation. En plus des mâchefers d'incinérateur, un agrégat standard (corindon) et un agrégat naturel (tout-venant) ont également été utilisés dans les essais de dommage mécaniques à des fins de comparaison. Des tests de traction et de poinçonnement ont été réalisés pour surveiller les changements dans les propriétés mécaniques des géotextiles lors des tests de dommages mécaniques. Les résultats, entre autres découvertes, ont révélé qu'il existe de bonnes perspectives pour l'utilisation des mâchefers d'incinérateur comme agrégat recyclé dans les applications de génie géotechnique, où elle peuvent être en contact avec des géosynthétiques.

KEYWORDS: Incinerator bottom ash; geotextiles; mechanical damage; recycled aggregates; sustainable development.

1 INTRODUCTION

Research and Development activities are a key stage to design innovative solutions involving the use of waste as raw materials, which is a global intention among the different industrial sectors in order to meet the aims of the United Nations Sustainable Development Goals (UN 2015). The reliability on the implementation of innovative solutions depends on how promising and consistent the outcomes resulting from scientific investigations are. Notwithstanding the need of finding useful roles for the different waste streams, it seems to be reasonable that efforts should be undertaken in order to provide sustainable solutions including the use of residues that are generated in considerable amounts. Incinerator bottom ash (IBA), which results from the incineration process of municipal solid waste, fits in the previously mentioned vision.

Over the last years, the use of IBA as raw material has been the target of investigations within different scopes in the domain of engineering. In this context, three important topics have been discussed with promising findings: 1) the use of IBA for producing alternative cementitious materials (Filipponi et al. 2003; Garcia-Lodeiro et al. 2016; Cristelo et al. 2020); 2) IBA as a recycled aggregate in the manufacturing of concrete (Pera et al. 1997; Müller and Rübner 2006; Kuo et al. 2013); and 3) the employment of IBA in road construction for performing the function of granular material (Hjelmar et al. 2007; Becquart et al. 2009; Townsend et al. 2020). In the third case, it is a common practice the use of geotextiles, which might come into contact with IBA.

Geotextiles are polymeric materials widely used in civil and environmental engineering to perform the following functions: filtration, drainage, separation, protection, and reinforcement. In the case of road construction, the procedures carried out during the installation on-site of geotextiles (e.g. their handling or the placement and compaction of layers of aggregate over them) may cause damage (mostly mechanical) in their structure, limiting their expected behaviour during service life. It is worth mentioning that, in many applications, geotextiles are exposed to the most considerable mechanical stresses upon installation (Hufenus et al. 2005; Shukla and Yin 2006). For this reason, in order to conclude about the suitability of using IBA as recycled aggregate in road construction in contact with geotextiles, it is essential to assess the level of mechanical damage that might be induced to these materials by IBA, as well as understanding if there are differences between the effect of IBA and reference aggregates on geotextiles.

The evaluation of the damage induced to geosynthetics during installation on-site can be conducted by performing laboratory or field tests (the latter are quite expensive since they require heavy equipment and a large team of skilled workers). The European normative EN ISO 10722 displays a method to induce mechanical damage under repeated loading on geosynthetics, which has been used in previous research works (Huang and Chiou 2006; Carneiro et al. 2013) to simulate the damage suffered by geosynthetics upon installation. The evaluation of the damage is usually accomplished by monitoring the changes occurring in the mechanical and hydraulic properties of the materials.

The main goal of this work was to evaluate the mechanical damage induced by IBA to four geotextiles (two woven and two nonwoven) in order to understand the effect caused by this residue in the mechanical properties of those construction materials. For achieving such purpose, the geotextiles were submitted to mechanical damage under repeated loading tests based on EN ISO 10722 with IBA, as well as with *corundum* (the aggregate used in the methodology included in the previously mentioned standard), and *tout-venant* (natural aggregate commonly used in road construction), for comparison purposes. Damage assessment included a visual inspection of the geotextiles after the damaging tests, followed by the performance of tensile and static puncture tests to monitor the mechanical behaviour of the materials.

2 MATERIALS AND METHODS

2.1 *Geotextiles*

The laboratory work was carried out using four geotextiles with different structures: two nonwoven made from polypropylene fibres (designated as geotextiles NW1 and NW2), and two woven produced with high-density polyethylene filaments (named as geotextiles W1 and W2). The mass per unit area and thickness of the geotextiles (determined in accordance with the standards EN ISO 9864 and EN ISO 9863-1, respectively) can be seen in Table 1 (values are presented with 95% confidence intervals obtained according to Montgomery and Runger (2010)). Geotextiles with these physical properties may be used to perform functions of filtration and/or separation in engineering projects. The sampling and preparation of test specimens was carried out according to EN ISO 9862.

Table 1. Physical properties of the geotextiles.

Geotextile	Mass per unit area ($g.m^{-2}$)	Thickness (mm)
NW1	112 (± 6)	1.07 (± 0.10)
NW2	313 (± 17)	2.66 (± 0.18)
W1	81 (± 1)	0.54 (± 0.01)
W2	204 (± 1)	0.88 (± 0.01)

(95% confidence intervals in brackets)

It was decided to use in this experimental campaign geotextiles having relatively low mass per unit area. This option was made in order to try to ensure the existence of a considerable level of degradation that could allow distinguishing the effect caused on the geotextiles by the different aggregates. It is possible that in the case of being used geotextiles with a very high mass per unit area the level of induced damage would be minimum, resulting in slight changes of the mechanical properties of the materials. With the non-existence of relevant damage, it would not be possible to distinguish the effect of the different aggregates.

2.2 *Aggregates*

The three aggregates used in the mechanical damage (MD) under repeated loading tests (hereinafter MD tests) were IBA (provided by a Portuguese incineration plant (LIPOR II - Maia)), *corundum* (synthetic aggregate made from aluminium oxide employed in the tests described in EN ISO 10722), and *tout-venant* (natural well-graded untreated mixed aggregate) (Figure 1). The particle size distribution of these aggregates, which can be seen in Figure 2, was evaluated by conducting the sieving method displayed in EN 933-1.

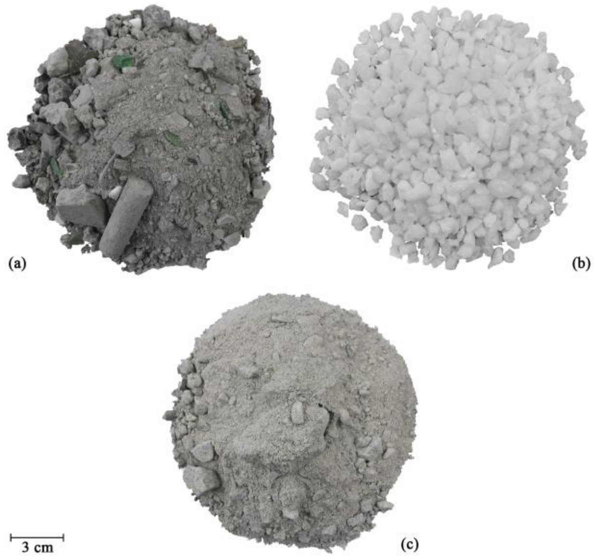

Figure 1. Aggregates used in the MD tests: (a) IBA; (b) *corundum*; (c) *tout-venant*.

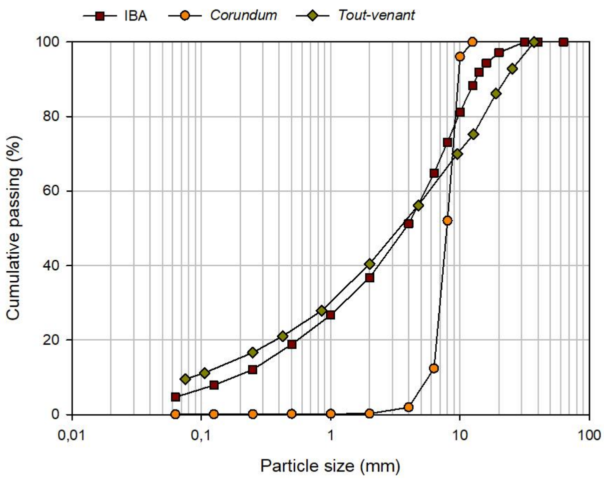

Figure 2. Particle size distribution of the aggregates.

2.3 *Mechanical damage under repeated loading tests*

The MD tests were performed according to the procedures of EN ISO 10722 in a prototype equipment developed at the Faculty of Engineering of the University of Porto, using the aggregates mentioned in Section 2.2 (detailed information about the equipment can be found in Lopes and Lopes (2003)). In sum, the tests included the placement of a specimen of geotextile between two layers of aggregate (each with a height of 75 mm), which were introduced into two square base boxes (each having a side of 300 mm and a height of 87.5 mm). The layer of aggregate placed in the lower box was divided into two sublayers with the same height (37.5 mm), which were submitted to a compaction process (application of a pressure of (200 ± 2) kPa for 60 s over a flat metal plate covering the whole area of the layers). On the contrary, the layer placed in the upper box was not divided into sublayers, nor subjected to a compaction process. The damaging actions were accomplished by using a loading plate (length and width of 200 and 100 mm, respectively) to apply a vertical dynamic loading between (5.0 ± 0.5) kPa and (500 ± 10) kPa at a frequency of 1 Hz for 200 cycles over the upper layer of the aggregate. The work plan for the MD tests (Table 2) involved the use of 100 specimens of geotextiles (half of them were afterwards submitted to tensile tests, and the remaining to puncture tests).

Table 2. Work plan for the MD tests.

	Number of specimens		
Geotextile	IBA	*Tout-venant*	*Corundum*
NW1	10	—	10
NW2	10	10	10
W1	10	—	10
W2	10	10	10

2.4 *Visual inspection and mechanical characterisation tests*

The damage induced by the MD tests to the geotextiles was assessed, in a first stage, through visual inspection, which can be useful to help understanding the possibility of the occurrence of changes in the properties of those construction materials. Later, tensile and static puncture tests were performed to quantify variations in the mechanical behaviour of the geotextiles.

Tensile tests were conducted in accordance with EN ISO 10319 on a *Lloyd Instruments LR50K* testing machine fitted with a load cell of 10 kN. The specimens used in these tests, which were prepared and tested in the machine direction of production of the geotextiles, had a length (between grips) and a width of, respectively, 100 and 200 mm. The tests were performed under displacement control at 20 mm.min^{-1}. Tensile strength (T, in kN.m^{-1}) and elongation at maximum load (E_{ML}, in %) were the parameters resulting from the tensile tests.

The static puncture tests were performed in the previously mentioned *Lloyd Instruments LR50K* testing machine under displacement control at 50 mm.min^{-1}, taking into account the standard EN ISO 12236. The specimens used in these tests had a diameter of 150 mm between the clamping rings. Puncture strength (Fp, in kN) and push-trough displacement (h_p, in mm) were the properties evaluated through the puncture tests.

The values of the mechanical properties of the geotextiles presented in Section 3 resulted from the arithmetic mean of five tested specimens and are presented with 95% confidence intervals determined according to Montgomery and Runger (2010).

3 RESULTS AND DISCUSSION

3.1 *Visual inspection*

The MD tests caused distinct types of damage on the geotextiles, depending on the used aggregate and on the structure of these materials. Besides punctures and abrasion, the damaging tests also induced cuts of components (fibres or filaments with regard to, respectively, nonwoven or woven geotextiles). In addition, the action of some aggregates led to the formation of holes in the structure of nonwoven geotextiles, as well as the crushing of filaments in woven geotextiles. Table 3 displays the types of damage observed in the geotextiles after the MD tests, which were graded into the following four levels: 0 (not detected); 1 (low); 2 (medium); 3 (high). Due to the nature of the structure of the materials, no grade was ascribed to the types of damage "holes" and "crushed filaments" regarding, respectively, the woven and nonwoven geotextiles.

Table 3. Evaluation of the damage observed in the geotextiles after the MD tests.

Geotextile	Aggregate	Cuts	Punctures	Abrasion	Holes	Crushed filaments
NW1	IBA	1	1	1	1	—
	Corundum	2	2	2	1	—
NW2	IBA	1	1	1	0	—
	Corundum	2	2	2	0	—
	Tout-venant	1	1	1	0	—
W1	IBA	2	1	1	—	1
	Corundum	3	2	2	—	1
W2	IBA	1	1	1	—	2
	Corundum	2	2	2	—	3
	Tout-venant	1	1	1	—	1

The visual analysis conducted on geotextiles NW1 and NW2 revealed that the damage induced by the MD tests was slightly more pronounced in geotextile NW1 due to presence of small holes, which were not detected in geotextile NW2. In terms of cuts in fibres, punctures and abrasion promoted by the MD tests, no relevant differences were found between geotextiles NW1 and NW2. Comparing the effect of the aggregates, the damage caused by the MD tests with *corundum* on both geotextiles was more significant than that observed after the MD tests with IBA. It is also worth mentioning that the effect of the MD tests with IBA and *tout-venant* on geotextile NW2 was quite similar in terms of the degree of damage detected during this stage.

The MD tests induced relevant damage in the structure of the woven geotextiles. The structure of geotextile W1 was severely affected by the action of both IBA and *corundum*, being the damage more pronounced when the latter was the aggregate used in the MD tests. The most considerable aspect was the cut of filaments, which led to a partial destruction of the structure of geotextile W1. This outcome was more meaningful when *corundum* was the used aggregate. With regard to geotextile W2, it is important to mention that the damage caused by IBA was relatively similar to the damage caused by *tout-venant*, but less pronounced compared to *corundum*. Although the number of cut filaments in geotextile W2 was lower compared to geotextile W1, the number of crushed filaments after the MD tests was higher, especially when *corundum* was the used aggregate.

3.2 *Tensile and puncture behaviours*

3.2.1 *Nonwoven geotextiles*

The damage observed during the visual inspection suggested the occurrence of some changes in the mechanical properties of the nonwoven geotextiles. Indeed, the suspicions were confirmed, as can be noticed in Tables 4 and 5, which display the tensile and puncture properties of geotextiles NW1 and NW2, respectively.

The MD tests with IBA led to reductions in the tensile and puncture strengths of the nonwoven geotextiles, being the losses much more pronounced in geotextile NW1 (55.9% and 59.9%, respectively) than in geotextile NW2 (reductions of 13.9% and 16.9%, respectively). Since only minor damage was observed in geotextile NW1 during the visual inspection, the considerable reduction (for less than half) of its mechanical strength was not expected. The reason for such outcome might be related to the existence of damage undetectable to the naked eye. On the other hand, the changes found in the mechanical strength of geotextile

NW2 after the MD tests with IBA corroborated the outcomes of the visual inspection, in which no serious damage was found in the nonwoven structure (Table 3).

Table 4. Tensile and puncture properties of geotextile NW1.

MD test	T (kN.m^{-1})	E_{ML} (%)	F_p (kN)	h_p (mm)
Undamaged	8.80 (± 1.13)	70.3 (± 11.7)	1.37 (± 0.20)	56.8 (± 6.5)
IBA	3.88 (± 0.53)	41.4 (± 7.6)	0.55 (± 0.20)	37.7 (± 6.8)
Corundum	2.27 (± 0.60)	37.9 (± 14.8)	0.38 (± 0.12)	34.6 (± 3.4)

(95% confidence intervals in brackets)

Table 5. Tensile and puncture properties of geotextile NW2.

MD test	T (kN.m^{-1})	E_{ML} (%)	F_p (kN)	h_p (mm)
Undamaged	14.80 (± 2.47)	71.6 (± 6.5)	2.72 (± 0.27)	64.6 (± 5.2)
IBA	12.74 (± 0.89)	59.1 (± 4.7)	2.26 (± 0.38)	52.5 (± 4.2)
Corundum	6.91 (± 1.07)	38.5 (± 2.9)	1.22 (± 0.32)	45.4 (± 3.4)
Tout-venant	11.53 (± 1.19)	52.9 (± 7.9)	1.96 (± 0.27)	50.9 (± 5.3)

(95% confidence intervals in brackets)

The results allow stating that *corundum* was the aggregate that led to the most relevant losses in the mechanical properties of the nonwoven geotextiles. In the case of geotextile NW1, the tensile and puncture strengths decreased considerably (the reductions in these parameters were of 74.2% and 72.3%, respectively), while for geotextile NW2 the losses were not so stressed (53.3% and 55.1%, respectively). This is in agreement with the findings of the visual inspection, which revealed that the level of damage imposed by *corundum* to the geotextiles was higher compared to the other aggregates.

With regard to the MD tests with *tout-venant*, the reductions found in the tensile and puncture strengths of geotextile NW2 (22.1% and 27.9%, respectively) were slightly higher than those induced by the tests with IBA, but considerably lower compared to the losses promoted by the tests with *corundum*. Taking into account the 95% confidence intervals, the differences observed between the tensile and puncture strengths of geotextile NW2 after the MD tests with IBA and *tout-venant* may not be very significant.

A comparison of the results obtained for tensile and puncture strengths allows concluding that both properties suffered similar changes when evaluating the effect of the same aggregate. Indeed, and as indicate above for each aggregate, the reductions found in these two mechanical properties were very close.

Concerning the elongation at maximum load and push-trough displacement of geotextiles NW1 and NW2, the MD tests also promoted some changes on these properties. C*orundum* tended to be the aggregate responsible for the highest reductions on the aforementioned properties (although, in some cases, the losses were not remarkably different from those induced by the other aggregates), while the effects of IBA and *tout-venant* were very close taking into account the 95% confidence intervals.

Finally, a relevant feature that should be highlighted is that geotextile NW2 proved to be more resistant (better preservation of the mechanical properties) against the damaging actions than geotextile NW1. This circumstance underlines the important role that mass per unit area plays on the survivability of geotextiles submitted to MD tests, i.e., the increase of the mass per unit area tends to result in a better resistance against degradation. Actually, this trend was also observed, for example, in the works of Carlos et al. (2015) and Carlos et al. (2019).

3.2.2 *Woven geotextiles*

The results of the tensile and static puncture tests carried out on geotextiles W1 and W2 (displayed in Tables 6 and 7, respectively) revealed that the mechanical behaviour of the materials was, as previously observed for the nonwoven geotextiles, distinctively affected, depending on the aggregate used in the MD tests.

Table 6. Tensile and puncture properties of geotextile W1.

MD test	T (kN.m^{-1})	E_{ML} (%)	F_p (kN)	h_p (mm)
Undamaged	11.48 (± 0.40)	29.4 (± 3.5)	1.60 (± 0.03)	39.8 (± 1.0)
IBA	4.35 (± 0.78)	11.4 (± 1.5)	0.76 (± 0.16)	33.3 (± 3.4)
Corundum	2.52 (± 0.25)	10.8 (± 3.6)	0.09 (± 0.04)	18.4 (± 3.6)

(95% confidence intervals in brackets)

Table 7. Tensile and puncture properties of geotextile W2.

MD test	T (kN.m^{-1})	E_{ML} (%)	F_p (kN)	h_p (mm)
Undamaged	27.96 (± 0.52)	53.7 (± 2.2)	4.23 (± 0.20)	50.0 (± 5.2)
IBA	19.18 (± 1.03)	30.8 (± 3.1)	2.38 (± 0.24)	42.4 (± 1.9)
Corundum	13.26 (± 0.88)	20.2 (± 1.0)	1.45 (± 0.09)	31.5 (± 8.3)
Tout-venant	24.70 (± 0.56)	39.7 (± 3.0)	3.26 (± 0.38)	40.5 (± 3.6)

(95% confidence intervals in brackets)

Corundum was, again, the aggregate responsible for imposing the most accentuate losses in both tensile and puncture strengths of geotextiles W1 and W2. Those reductions were quite more pronounced in geotextile W1 (78.0% and 94.4%, respectively), which was an expected outcome considering that the MD tests with *corundum* resulted in the cutting of a large number of the filaments composing the woven structure. It is worth noting that when the filaments are cut, these elements no longer contribute to the mechanical strength of woven geotextiles. With respect to geotextile W2, the main features that may have led to the losses found in its tensile and puncture strengths (52.6% and 65.7%, respectively) were the cutting of filaments, which occurred on a smaller scale compared to geotextile W1, and the high number of crushed filaments. The latter generated the reduction of the cross-section of the filaments, weakening the resistance of geotextile W2 (when the filaments are crushed, failure occurs more easily). In both geotextiles, the punctures and abrasion detected on the woven structure may also have contributed to the losses found in mechanical strength, however, predictably on a smaller scale than the cuts (whose effect immediately results in a reduction of mechanical strength).

The MD tests with IBA also caused changes in the tensile and puncture strengths of the woven geotextiles. In geotextile W1, the losses found in the aforementioned properties were of 62.1% and 52.5%, respectively, whereas in geotextile W2 the reductions were not so high: 31.4% and 43.7%, respectively. The differences observed in the mechanical strength of these two geotextiles after the MD tests with IBA is in accordance with the outcomes of the visual inspection, which revealed that the cutting of filaments was more pronounced in the woven structure of geotextile W1 (Table 3). In the case of geotextile W2, the higher number of crushed filaments compared to geotextile W1 and the cutting of filaments might have been the main types of damage contributing to the losses observed in its mechanical strength.

The MD tests with *tout-venant* caused the lowest reductions in the tensile and puncture strengths of geotextile W2 (11.7% and 22.9%, respectively). These less significant reductions were not surprising giving the low level of damage detected during the visual inspection. Comparing *tout-venant* with IBA, the latter led to a higher crushing of filaments during the MD tests. This aspect explains the lower deterioration of the mechanical strength of geotextile W2 when *tout-venant* was used as aggregate.

The losses found in the tensile and puncture strengths of the woven geotextiles after the MD tests did not follow the trend that was noticed for the nonwoven geotextiles, in which similar losses of the two mechanical properties were observed when analysing the effect of the same aggregate. Indeed, in the woven geotextiles, the losses observed in puncture strength tended to be higher than those found in tensile strength. The only exception was noticed after the MD tests of geotextile W1 with IBA.

With respect to elongation at maximum load and push-trough displacement, the MD tests with *corundum* were responsible for reductions in these properties that tended to be higher than those induced by the MD tests with IBA or *tout-venant*. Comparing the effect of these last two aggregates on geotextile W2, IBA caused a more significant loss in elongation at maximum load than *tout-venant*. Regarding the push-trough displacement, the difference between the effects of these two aggregates was not so marked, being the values close considering the 95% confidence intervals.

The comparison of the results obtained for geotextiles W1 and W2 allowed to conclude that the increase of mass per unit area resulted in a better survivability of these materials in the MD tests. This is in agreement with the results found in Section 3.1 for the nonwoven geotextiles.

3.3 *Overview on the effect of IBA on geotextiles*

The implementation of engineering solutions involving the use of IBA as recycled aggregate in contact with geotextiles requires understanding the impact of this residue on those construction materials, and a further comparison with other aggregates. Figure 3 shows a comparison between the residual tensile and puncture strengths of the geotextiles after the MD tests with the different aggregates. Residual strengths (in %) were obtained by dividing the strengths of damaged samples by their counterparts resulting from undamaged samples.

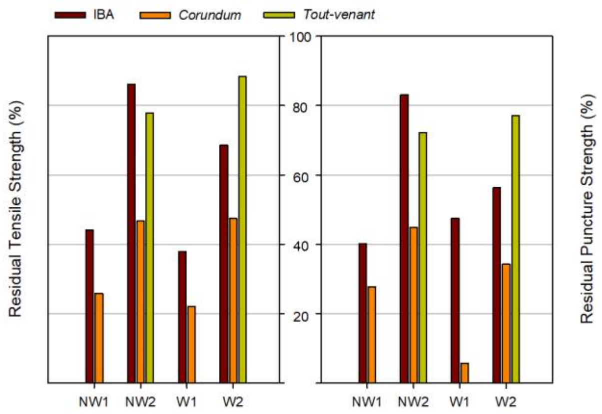

Figure 3. Residual tensile and puncture strengths of the geotextiles.

The use of IBA during the MD tests led to the degradation of the mechanical strength of the geotextiles, an outcome that was more pronounced for the materials with lower mass per unit area. As can be observed in Figure 2, IBA was a well-graded aggregate, a feature that contributed to the formation of a relatively regular and plane surface after the compaction of its sublayers during the MD tests. This resulted in a large contact area between IBA and the geotextiles, which may have contributed to a relatively good distribution of the applied loads. However, the presence of pieces of broken glass, sharp metal objects and ceramic particles with angular shape in the composition of IBA (constituents with the ability to induce cuts of fibres or filaments) induced damage on the woven and nonwoven structures, leading to the deterioration of the mechanical properties of the geotextiles.

As shown in Figure 3, *corundum* was the aggregate leading by far to the highest reductions in the mechanical strength of the geotextiles. This outcome can be explained by the characteristics of *corundum*, which is a poorly-graded aggregate (as can be seen in Figure 2) formed by angular rough particles with an irregular geometry and a high abrasive effect. These particles were capable of inducing extensive damage in the structure of the geotextiles, resulting in a high deterioration of their mechanical behaviour.

Concerning *tout-venant*, which is usually employed as filling material in civil engineering applications, results shown that this aggregate did not cause a severe deterioration of the mechanical behaviour of the geotextiles. In the case of geotextile NW2, the residual tensile and puncture strengths after the MD tests with *tout-venant* tended to be slightly lower than those obtained with IBA. By contrast, the residual tensile and puncture strengths of geotextile W2 were higher when *tout-venant* was the aggregate used in the MD tests. As can be observed in Figure 2, *tout-venant* was, as IBA, a well-graded aggregate (it is worth noting that the particle size distribution of *tout-venant* and IBA was quite similar) having particles of relatively high dimension with an irregular geometry and angular shape. The isolated action of these larger particles can induce damage on the geotextiles. However, their potential negative effect was not emphasized due to the significant amount of fine particles that were surrounding those larger particles. As explained above for IBA, due to the fact that *tout-venant* was a well-graded aggregate, the compaction steps of the MD tests resulted in the formation of a fairly flat surface, promoting a large contact area between the geotextiles and the aggregate and allowing a good distribution of the applied loads.

Considering the promising results in terms of the mechanical damage induced to geotextiles by IBA (it was observed that the impact of IBA was low compared to *corundum*, and only higher than the effect of *tout-venant* in one of the two cases tested), it seems reasonable to exploit the idea of designing sustainable geotechnical engineering applications comprising the use of this residue as filling material in contact with geotextiles. However, in order to assign this role to IBA, issues other than the effect of this residue on the short-term behaviour of geotextiles should be examined. In this context, it should also be studied the effect of IBA on the long-term behaviour of geotextiles to understand the possibility of occurring undesirable changes in their properties over time. In addition, it is also of utmost importance to perform a full characterisation of IBA in terms of its physical, mechanical and chemical properties (e.g., assessment of fines, resistances to fragmentation and wear, determination of water-soluble sulphate content, and chemical composition). An unavoidable chemical issue to be examined is the environmental behaviour of IBA in order to determine if this residue contains hazardous substances that can be released into soil or water, endangering human health and the environment. The foregoing aspects are essential to the possible use of IBA as filling material and studies are underway to clarify them. If the doubts associated with the previous issues are overtaken, there will be strong reasons to invest in the development of sustainable solutions in the field of geotechnical engineering comprising the use of IBA as a noble raw material.

4 CONCLUSIONS

This work focused on the study of the effect of IBA (a residue resulting from the incineration process of municipal solid waste) on the short-term mechanical behaviour of woven and nonwoven geotextiles by conducting MD tests with that residue, as well as with two other aggregates for comparison purposes: *corundum* (standard aggregate) and *tout-venant* (natural aggregate). The following main findings arose from the results obtained in this work:

- The MD tests with IBA had a lower effect on the tensile and puncture properties of the geotextiles than the MD tests with *corundum*.
- It was noticed that the MD tests with *tout-venant*, which is an aggregate commonly used as filling material, resulted in slightly higher losses in the tensile and puncture strengths of the nonwoven geotextile than the tests with IBA. On the contrary, IBA was responsible to cause higher reductions in those properties in the case of the woven geotextile.
- Taking into account the effect of the MD tests with IBA on the geotextiles, it is reasonable to consider the possibility of using this residue as filling material in engineering works where it will have contact with geotextiles.
- The increase of the mass per unit area of the geotextiles led to a better survivability of the materials to the MD tests. If geotextiles with higher mass per unit area had been tested, the effect of IBA would be predictably less pronounced.
- A complete characterisation of the physical, mechanical and chemical properties of IBA is necessary in order to decide about the suitability of turning this residue into a recycled aggregate to accomplish the function of filling material in engineering projects. Further studies are already in progress to fulfil this need.

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