EuroGeo4 Paper number 283

PRECISE HYDRAULIC CONDUCTIVITY MEASUREMENTS ON TIRE DERIVED AGGREGATE

Enrique Romero[1], Ignacio Sanmartin[2], Marcos Arroyo[3] & Antonio Lloret[4]

[1] *UPC -Department of Geotechnical Engineering and Geosciences. (e-mail: enrique.romero-morales@upc.edu)*
[2] *UPC -Department of Geotechnical Engineering and Geosciences.*
[3] *UPC -Department of Geotechnical Engineering and Geosciences.*
[4] *UPC -Department of Geotechnical Engineering and Geosciences.*

Abstract: Tire derived aggregate (TDA) might be employed as a substitute for other granular materials in civil engineering structures. It has several attractive properties, like being lightweight, very permeable and a good thermal insulator. The high permeability of TDA is exploited in landfill covers and other uses are now being explored.

The high compressibility of TDA results in hydraulic conductivity varying by orders of magnitude within the range of mechanical loads possible in field applications. Due to clogging, similar order of magnitude variations in hydraulic conductivity are possible due to biological and chemical loading, when draining leachates. For laboratory studies of the hydraulic properties of TDA it is therefore necessary to ensure measurement precision within a large range.

This communication presents a novel method for the measurement of TDA hydraulic conductivity, using differential pressure transducers. Results of a study on tire derived aggregates of different nominal size subject to oedometric loading are shown to illustrate the advantages and capabilities of the method.

Keywords: tire chip, hydraulic conductivity, laboratory test.

INTRODUCTION

During the last decade disposal of used tires has been a subject of major regulatory activity in Europe in general and Spain in particular. The EU Landfill Directive (1999) forbade the landfill disposal of whole tires since 2003 and of shredded tires since 2006. In 2001 Spain Environment ministry presented the first national plan on waste tire (PNNFU, MMA 2001). A hierarchy of waste management strategies was established: prevention, reuse, recycle, energy production and disposal, in that order of priority. The plan established a goal of 20% of total waste tire production recycled by 2006.

The last available statistics (MMA, 2007) indicate that currently about 300.000 tonnes of waste tires are generated per year in Spain. In 2005 (last year for which data is available) only 13,5% of the total production was recycled and still 50% of the residue was disposed of in landfills. Therefore there is still a large scope for improving the situation.

The use of shredded tires as tire derived aggregate (TDA, Humphrey, 2007) in civil engineering works has a number of benefits from the environmental viewpoint. First, it is a low-cost recycle product, because large sizes (up to 30 cm) might be employed and the production costs are lower than for finer materials. Second, it has a large consumption potential: thousands of tonnes of residue may be employed in a single project. Thirdly, exploiting its properties (mechanical, hydraulic, acoustic, thermal) may offer substantial improvements on construction costs in a number of circumstances.

One property of TDA fills of clear engineering interest is their high permeability. TDA fill has been already employed successfully as a draining layer in a number of civil engineering projects. The vast majority of these projects have been landfills, where TDA is used in capping or leachate collection layers, substituting gravel. There is clear field evidence (Aydilek et al. 2006) that TDA drainage layers perform well in those applications. New applications of TDA-made drainage layers are now been explored in embankments and other fills (Karmokar, 2008). Indeed, as the environmental concerns that once surrounded their application are progressively dissipated (Edil, 2008), the scope for applications of TDA-made draining layers is likely to increase.

Several laboratory studies of TDA hydraulic properties have been already reported (Reddy & Saichek, 1998; Hudson et al., 2003; Warith & Rao, 2006; Aydilek et al. 2006). Several of these studies (Reddy & Saichek, 1998; Hudson, 2003; Warith & Rao, 2006) have indicated experimental difficulties when measuring the large hydraulic conductivities that are expected when the material is less stressed. To explicitly address this point a new measurement system here described was set up for the measurement of hydraulic conductivity. The first experimental results obtained with this new system are here described.

This study of the hydraulic properties of TDA is part of a more ample research programme into the geotechnical properties of this material. One emphasis of the programme is to identify clearly the occurrence of size-dependent phenomena in the tests, with the final aim of assessing the validity, or otherwise, of smaller TDA aggregates as model materials for the larger sizes prevalent in the field. Our previous work (Arroyo et al. 2008) showed, for instance, that response under direct shear and oedometric loading is size-independent. This issue is also explored here in connection with hydraulic conductivity by using two different sized materials.

EXPERIMENTAL DETAILS

Material

Several samples of TDA were sent from a commercial shredding operation to the geotechnical laboratories at UPC. The granulometric curves of these samples are presented here in Figure 1.The main identification characteristics of the samples are summarized in table 1, including median grain diameter, D50 specific weight, G, initial water content, w_{ini}, maximum adsorbed water w_{max}. The smaller sized samples have a slightly more uniform granulometric curve, a consequence of their being obtained at a later stage on the shredding process. The initial water content represents the water adsorbed at the relative humidity prevalent in the laboratory atmosphere (around 50%). The maximum water content represent the water adsorbed in the sample after prolonged immersion in water. The TDA samples here employed had an insignificant amount of exposed or free metallic fragments, both defined in accordance with ASTM D6270.

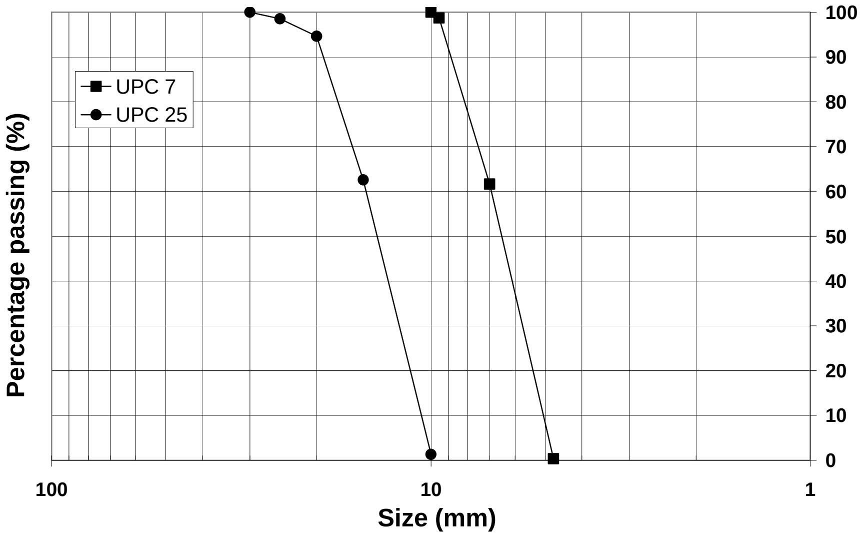

Figure 1. Granulometric curves of the TDA samples employed in this study

Table 1. Characteristics of the TDA samples employed in this study

Sample	D_{max} mm	D_{50} mm	C_u	G	w_{ini} %	w_{max} %
UPC 7	10	6.6	1.35	1.11	0.43	6.92
UPC 25	30	14	1.39	1.22	1.45	6.19

Equipment

A large brass oedometer of 300 mm diameter was employed for the tests here described. The apparatus is illustrated in Figure 2. Tests were performed under controlled load conditions. Load was applied on top of the sample by means of a membrane pressurized with air. The 300 mm oedometer had three load cells located below the base plate to allow for side friction. Vertical displacements were measured on top of the sample using an LVDT.

Water flow through the sample was from bottom to top, were water ports were located. To ensure homogeneous flow through the sample section, a perforated plate was located at both ends. The flow of water was measured using a scale to weigh the water mass at the outlet port of the system and timing the flow period. Measurement of water pressure was done by means of three open holes on the sample side, alternatively connected by pairs to a differential pressure transducer. This transducer had a resolution of 0.75Pa. Since the distance between the measuring ports was 88 mm, this arrangement was able to resolve hydraulic gradients below 10^{-3}.

Figure 2. Side view of the adapted oedometric cell. Note the lateral ports connected to the DPT on top of the cell.

Test procedure

The TDA samples were just poured into the container without compaction. After saturation, the samples were subjected to monotonic increases in vertical load, up to a vertical applied load of 400 kPa. No lubricant was employed to reduce side friction, to avoid problems with the lateral hydraulic pressure measurements. The absence of lubricant resulted in a very high side friction, with only about 25% of the applied top load being detected by the bottom load cells. The bottom and top measured pressures were averaged to obtain a representative vertical stress on the sample. The maximum average stress thus reached was around 250 kPa.

Hydraulic testing took place at every load step, inducing flow through the sample and measuring the head loss. On several steps, the input flow to the sample was varied to observe the eventual variation of head loss with flow rate.

RESULTS

Compressibility

Samples of TDA are known to be highly compressible, and the ones here tested were not an exception to this rule. In Figure 3 the evolution of sample porosity with average sample stress is represented for three different samples. The smaller sized material (UPC 7) achieves a more compact packing than the one with larger particles (UPC 25). However, as shown by the curve slopes, both sizes show very similar compressibility, particularly when the average stress exceeds 20 kPa. This result is in agreement with previous tests reported by the authors (Arroyo et al, 2008) where, employing variously sized TDA samples and oedometric apparatuses, no evidence for a size-effect on compressibility was found.

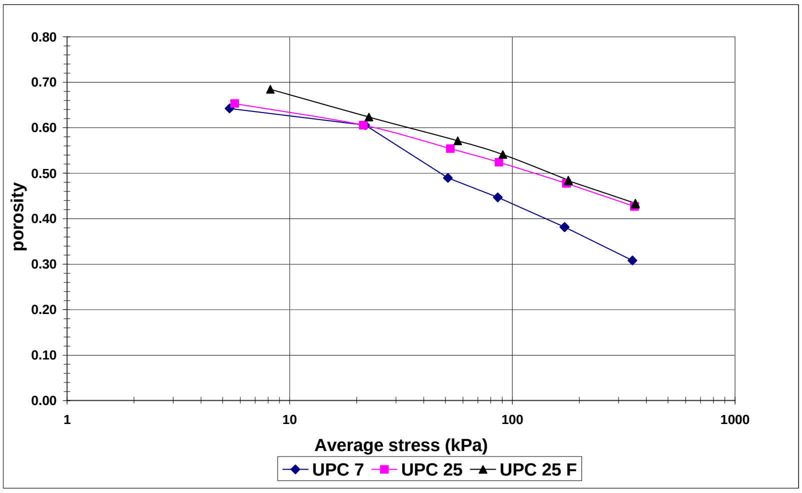

Figure 3. Porosity vs average stress for the TDA samples

Hydraulic conductivity

The measured hydraulic conductivity is represented as a function of the average vertical stress on Figure 4. In the range explored the conductivity falls almost two orders of magnitude for both TDA sizes. As expected, the smaller sized, more closely packed UPC7 sample always has lower conductivity than the larger-sized UPC25 samples.

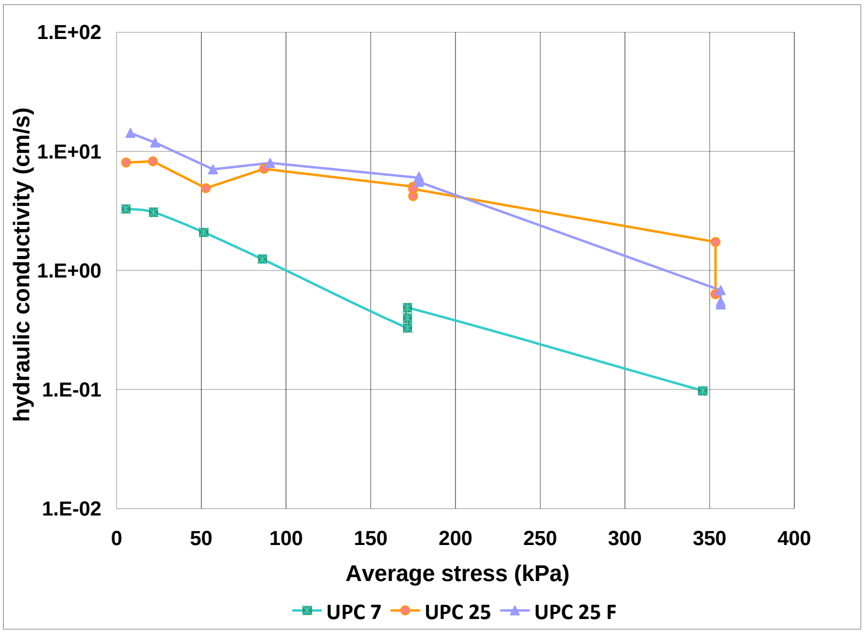

Figure 4. Hydraulic conductivity vs average stress for the TDA samples

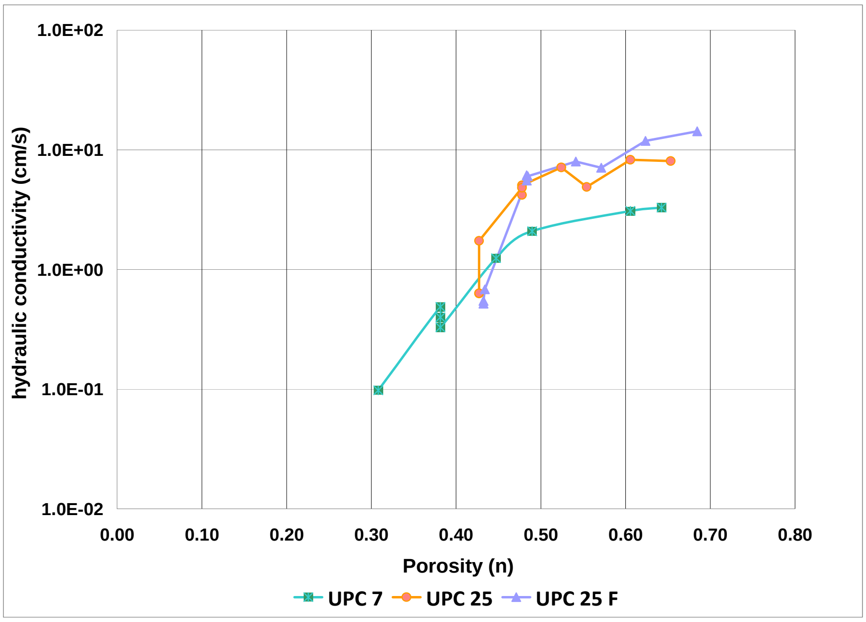

Figure 5. Hydraulic conductivity vs porosity for the TDA samples

In Figure 5 the measured hydraulic conductivity is represented as a function of the sample porosity. It appears that the influence of the granulate size on the conductivity is overridden by that of porosity as the porosity decreases. At large porosity values the two different TDA sizes show clearly different values of hydraulic conductivity, even at similar values of porosity.

In several instances varied flow rates were employed to measure permeability while keeping the porosity constant. The observed head loss at every flow rate is shown in Figure 6. Even if there are some isolated inconsistencies in the results, the general trend is one of diminishing secant permeability with increasing flow rate, as shown in Figure 7.

This trend is consistent with what is expected from non-darcian flow models, (Bear, 1972). However, the experiments only covered a relatively moderate range (between 1 and 15) of the relevant Reynolds number and, therefore, the onset of non-darcian flow was not very clear.

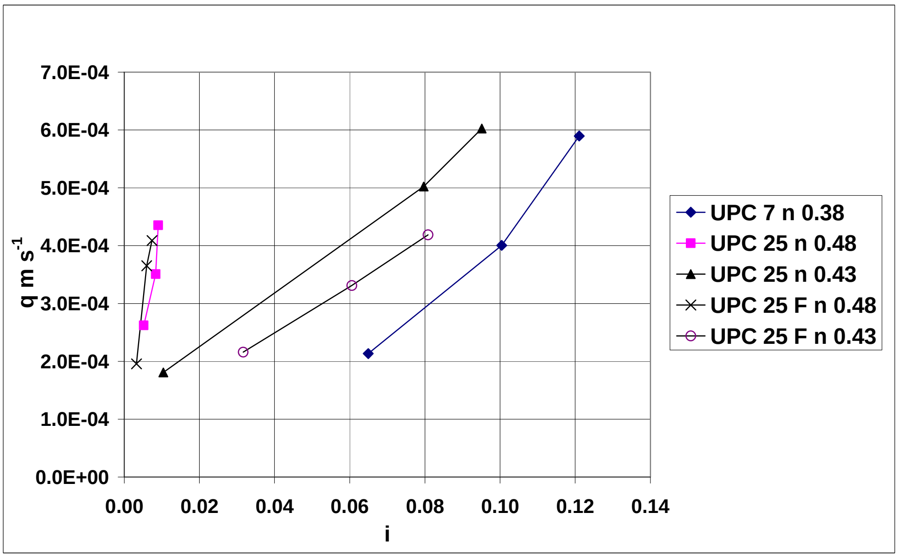

Figure 6. Relation between flow rate and head loss at various porosities

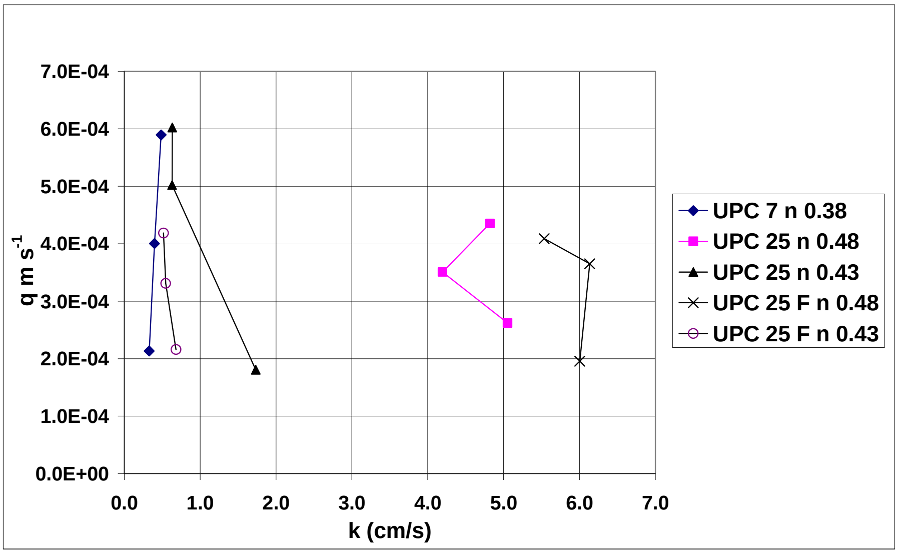

Figure 7. Relation between flow rate and secant hydraulic conductivity

DISCUSSION

The relation between porosity and vertical stress deduced from data on previous studies is plotted alongside that here obtained in Figure 8. That for porosity and hydraulic conductivity it is shown in Figure 9. Basic granulometric data from previous studies are collected in Table 2.

There is a good overlap of the compressibility data on UPC25 and that of Warith & Rao (2006) and Reddy & Saichek (1998). In our data the larger sized material had larger porosities; this is compatible with the results from Aydilek et al (2006), but not so with those reported by Hudson et al, (2003) where the larger pieces employed apparently achieved much higher densities at similar stresses.

When considering the hydraulic conductivity values here measured there is a satisfactory range overlap with most data obtained in previous studies (Figure 9). It may be noticed that the conductivity range covered in the initial experiments made with the system presented here is wider than that obtained in any other previous campaign. Again, the results from Hudson et al are clearly outside the range from the others. Nevertheless, a more subtle difference appears in the dependency of hydraulic conductivity with porosity.

The Kozeny-Carman equation (see Bear, 1972; Chapuis & Aubertin, 2003) contains the following dependency of the hydraulic conductivity on the porosity

$$k = A\frac{n^3}{(1-n)^2} = AB(n)$$

where k is the hydraulic conductivity and n the porosity. The factor A accounts for dependency on other properties, like fluid properties, specific surface or tortuosity.

It is possible to compare directly the measured porosity dependency with that predicted by the Kozeny-Carman equation, if the measured permeability, k^m, is normalized according to the following expression

$$B(n) = \frac{k^m(n)\,B(n_0)}{k^m(n_0)}$$

This is done here in Figure 10. The values measured in this study are slightly above those predicted by the equation, but the trend is similar. The agreement with the equation is remarkably good for the measurements of Hudson et al. (2003), whereas the rest of the preceding measurements seem to indicate a stronger dependency on porosity.

Table 2. Granulometric characteristics of other TDA hydraulic studies

Sample	D_{max} mm	D_{50} mm	D10 mm	D60 mm	C_u
Reddy & Saichek	150	60	25	65	2.60
Hudson et al	200	150			
Warith & Rao	100	40	20	60	3.00
Aydilek et al	100	50			

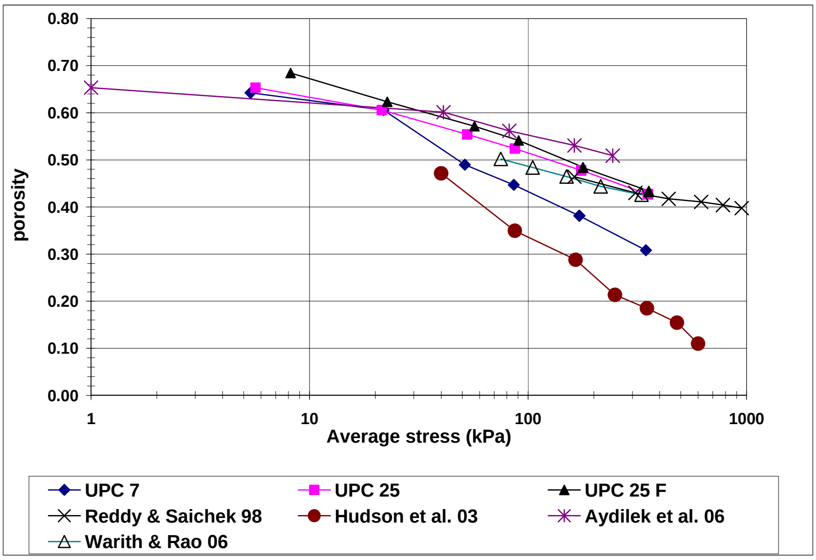

Figure 8. vertical stress vs porosity of TDA for this and other studies

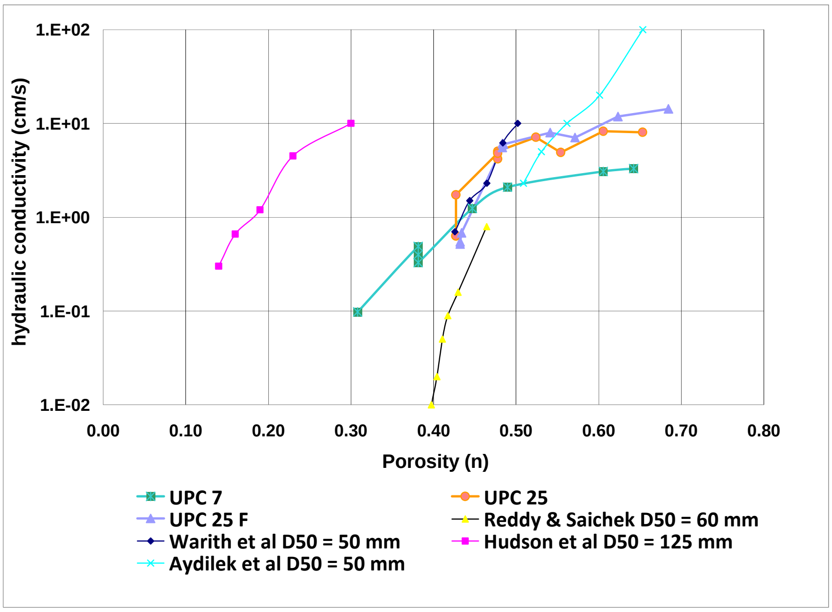

Figure 9. Hydraulic conductivity vs porosity of TDA for this and other studies

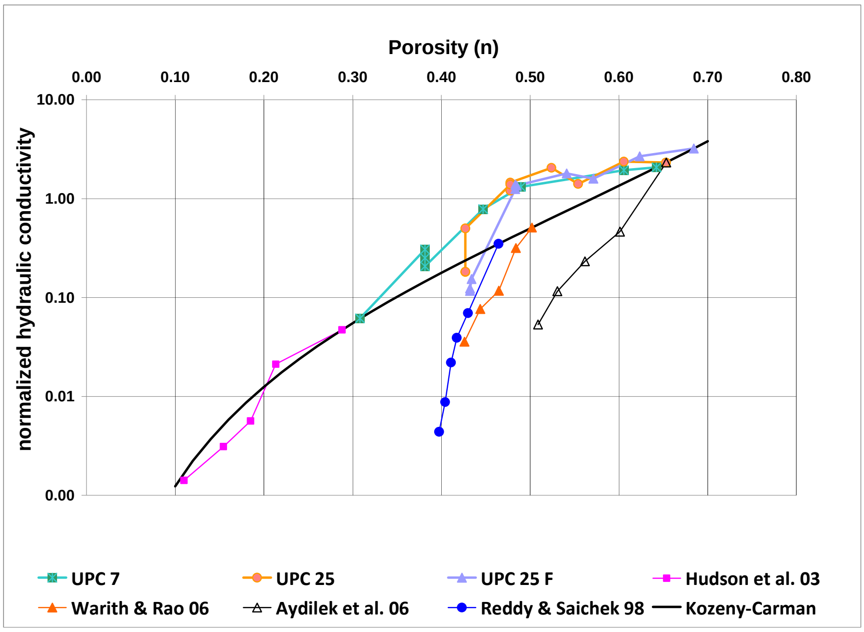

Figure 10. Dependency of hydraulic conductivity on porosity and Kozeny-Carman equation

SUMMARY

The hydraulic conductivity of various samples of TDA has been measured. The range of values obtained is similar to that of previous experimental campaigns. Our results indicate a closer correspondence with the Kozeny-Carman porosity dependence than that evident in most previous work. There are also some indications that non-darcian flow might take place at the higher porosities. The relevance of grain size properties to hydraulic conductivity is still not clear. To confirm and deepen these observations more experimental data is needed. These future measures would benefit of the hydraulic gradient measurement system here employed, a good tool to obtain very precise measures within a large range of hydraulic conductivity.

Acknowledgements: Francisco Mudoy helped with the experimental work described in this paper. This work is supported by the Spanish ministry of the environment (Ministerio de Medio Ambiente) through grant A157/2007/2-05.1

Corresponding author: Dr Marcos Arroyo, UPC -Department of Geotechnical Engineering and Geosciences, Jordi Girona 1-3 Modul D2, Barcelona, Spain. Tel: 0034689059351. Email: marcos.arroyo@upc.edu.

REFERENCES

Arroyo, M, Estaire, J., Sanmartin, I, Lloret, A. 2008. Size effect on tire derived agrégate mechanical properties, in Hazarika & Yasuhara (eds.) Scrap tire derived geomaterials: opportunities and challenges, Taylor & Francis, 151-160

ASTM 1998. Standard practice for use of scrap tires in civil engineering applications. ASTM D6270-98

Aydilek, A.H., Madden, E.T., & Demirkan, M.M. 2006. Field evaluation of a leachate collection system constructed with scrap tires. ASCE Journal of Geotechnical and Geoenvironmental Engineering, 132 (8), 990-1000

Bear, J. 1972. Dynamics of fluids in porous media. Elsevier, New York.

Chapuis, R. P., and Aubertin, M. 2003. “On the use of the Kozeny-Carman equation to predict the hydraulic conductivity of a soil.” Can. Geotech. J., 40, 3, 616–628.

Hudson, A.P., Beaven, R.P. & Powrie, W., 2003. Bulk compressibility and hydraulic conductivity of used tyres for landfill drainage applications. Proceedings Sardinia 2003: Ninth International Waste Management and Landfill Symposium, 6–10 October, CISA, Italy, 9 p.

Karmokar, A.K. (2008) Use of scrap tire derived shredded geomaterials in drainage application, in Hazarika & Yasuhara (eds.) Scrap tire derived geomaterials: opportunities and challenges, Taylor & Francis, 127-138

MMA, (2001), Waste Tire Management National Strategy, (Plan Nacional de Neumáticos Fuera de Uso, PNNFU), Ministerio de Medio Ambiente (in Spanish)

MMA, (2007), Draft Waste Management National Strategy (Borrador del Plan Nacional de Residuos), Ministerio de Medio Ambiente (in Spanish, draft available at http: // www.mma.es/ portal/ secciones/ calidad_contaminacion/ residuos/ planifica-cion_residuos/ borrador_pnir.htm)

Reddy, K.R. & Saichek, R.E. 1998. Characterization and Performance Assessment of Shredded Scrap Tires as Leachate Drainage Material in Landfills. Proceedings of the Fourteenth International Conference on Solid Waste Technology and Management, Philadelphia, Pennsylvania, November 1998

Warith, M.A. & Rao, S.M. 2006. predicting the compressibility behaviour of tire shred samples for landfill applications. Waste Management, 26, 268-276.