COMPARISON OF CRIMSON FOUNTAINGRASS AND DISS FIBRES AS AGGREGATES FOR CEMENT MORTARS

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Abstract
The use of natural fibres in cement composites is an expanding research field as their use can improve the mechanical and thermal behavior of cement mortars and reduce their carbon footprint. In this paper two different wild grasses, i.e. *Pennisetum Setaceum*, also known as crimson fountaingrass, and *Ampelodesmos Mauritanicus*, also called diss, are used as source of natural fibres for cement mortars. The principal aim is to evaluate the possibility of using the more invasive crimson fountaingrass in place of diss inside cement based vegetable concrete.
The two plants' fibres have been characterized by means of electron microscopy, helium picnometry; moreover, the thermal conductivity of fibre panels has been measured. Mortars samples using untreated and boiled fibres have been prepared. The mechanical characterization have been performed by means of three point bending and compression tests. Thermal conductivity and porosity have been measured to characterize physical modification induced by fibres' treatment. The results showed better thermal and mechanical properties of diss fibres composites than fountaingrass one and that fibres treatment leads to a decrease of thermal insulation properties.

Keywords:
Grass fibres, Ampelodesmos Mauritanicus, Pennisetum Setaceum, insulating plaster

1 INTRODUCTION

In the last decades, a considerable amount of interesting research has been carried out regarding the use of lignocellulosic materials in cementititous matrix for building applications. For their high sustainability and good physical and mechanical properties, natural fibres find practical applications in composite materials for automotive parts and building construction panels and furniture [Mohanty 2002 and Monteiro 2009]. Residues of sisal, banana tree and eucalyptus have been used as reinforcement of cement leading to good mechanical performance to the composites [Savastano 2000]. With the term *Agro-concrete* or *green concrete* is defined a mix between granulates from lignocellulosic plant (directly or indirectly from agriculture or forestry origin), which form the bulk of the volume, and a mineral binder [Sellami 2013].

In the present work the characterization of ecosustainable composite materials in the field of green building, for application as insulating plasters has been accomplished. Diss (*Ampelodesmos Mauritanicus*) and Crimson Fountaingrass (*Pennisetum Setaceum*), have been used as aggregates for cement mortars. *Pennisetum Setaceum* is an invasive plant that is progressively replacing the *Ampelodesmos Mauritanicus* in Italy [Badalamenti 2016]. Alien invasive plants represent one of the main threats to biodiversity on a global scale, and huge expenditure is required annually to prevent, control and eradicate them [Williamson 1996]. In Sicily, *Pennisetum Setaceum* is one of the most aggressive and rapid invaders of coastal and hilly areas. During the 70 years following its first introduction, it has established and spread over many coastal areas up to 600 m.a.s.l. and especially on south-facing slopes within the thermo-Mediterranean belt [Brullo 2010]. It has also invaded *H. hirta* thermo-xeric grasslands and even the more mesophilous *Ampelodesmos Mauritanicus* grasslands. It is likely to continue to spread into many other suitable localities, with significant and long-lasting ecological consequences [Corona 2016]. On the basis of these considerations, this research was aimed to evaluate the possibility of using crimson fountaingrass in place of diss, which in previous works has already been used as an aggregate for green concrete [Merzoud 2007 and Sellami 2013], in order to encourage the eradication of this invasive plant with fundamental benefits for the biodiversity of the territory.

2 MATERIALS AND METHODS

2.1 Raw materials

Diss (Ampelodesmos Mauritanicus)

Diss (*Fig. 51*) is a large grass widespread growing in the Mediterranean North Africa and in the dry regions of Greece to Spain, Balkans, Turkey and Asia Minoris. In France, it is found in the departments of Var, Southern Corsica, and Herault. It is a perennial plant of the Poaceae family, which lives on arid and sandy soils, often in pure associations, typical representatives of the Mediterranean grasslands. In Sicily, Ampelodesmos grasslands are commonly found from 0 to 1200 m a.s.l., chiefly within the meso Mediterranean and thermo-mediterranean bioclimatic belts [Brullo 2010]. It presents resistant leaves, up to 1 m long and about 7 mm wide, very rough, with margins later convoluted. The long and hard leaves can be sharp for the skin if rubbed between fingers. This plant was previously used in the realization of the old dwellings because of its mechanical and physical properties [Touati 2018]. Its fibrous trait, with thorny structure may confer high adhesion to the cement paste and hence promising properties to green concrete [Achour 2017]. In literature it is reported a Tensile Strength of 100 MPa, Density of 850g/cm^3, Modulus of Elasticity 2.17 GPa and a Water Absorption Coefficient at saturation of 112% [Merzoud 2011 and Yahiaoui 2011].

Fig. 114: Diss (Amelodesmos Mauritanicus) plant.

Crimson Fountaingrass (*Pennisetum Setaceum*)

Pennisetum Setaceum is a plant of the Poaceae family. The species is native to North Africa, the Middle East and the Arabian peninsula. Introduced by humans in many other geographic areas as an ornamental plant, it has proved to be a highly invasive species. It is a perennial herbaceous plant, with a bushy growth, up to 1,20m high. The ears are dark pink and gradually lighten with maturation, thus creating a variety of shades of color on the same plant. Pennisetum plant was introduced into Sicily as an ornamental plant during the 1940's and just twenty years later it began to regenerate naturally, spreading into surrounding areas [Pasta 2010]. Currently, it has successfully invaded many coastal and hilly areas up to 500m a.s.l., mainly on south-facing slopes within the thermo-Mediterranean bioclimatic belt [Brullo 2010].

Fig. 115: Crimson Funtaingrass (Pennisetum Setaceum) plant.

Binder (i.pro Plastocem)

The binder used in this work is *i.pro Plastocem* an Hydraulic Binder according to the UNI 10892-1 standard. The compression strength at 28 days is higher or equal than 3.0 MPa, it belongs to 3.0 class and is defined as "UNI 10892 LIC" 3.0. It is used for the production of mortars for internal and external plasters. PLASTOCEM is also suitable for the construction of mortars for masonry and substrates for floors. The result of the STA (*Fig. 116*) on the binder shows the presence of gypsum and calcium hydroxide, but no exothermic peaks associated with the presence of organic substances are observed; the content of calcium carbonate, linked to the final weight drop (30%), is around 68%. Therefore, it is possible to asses that it is a predominantly cement-based binder.

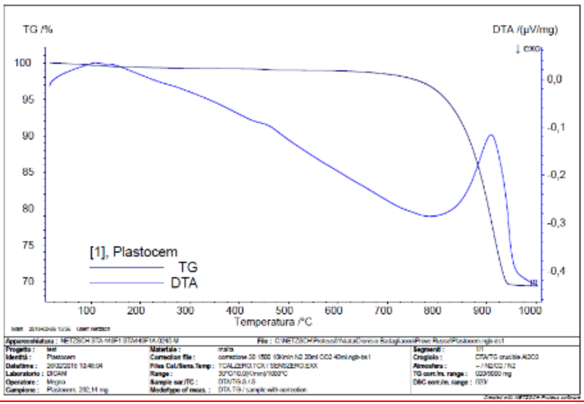

Fig. 116: STA result of the Hydraulic Binder (i.pro Plastocem).

2.2 Preparation of the fibres

The fibres used for their physical and chemical characterization and for the preparation of the mortars were obtained, for both the plants, as follows:

- The stems were cut from the raw plants and dried in oven at a temperature of 70 °C for 72 hours until constant mass, in order to minimize the influence of the moisture content and hence to standardize the physical characteristics of the fibres. The drying temperature was set to 70°C since it allows a relative rapid drying of the fibres, which is preferable for the industrialization of the process, without altering the chemical structure as evidenced by the STA results (*Fig. 122*);
- After drying, part of the stems were thermally treated by boiling for 4 hours with distilled water in order to remove the sugars and extractives and then repeatedly washed with distilled water to clean their surface. This treatment was performed because the dissolution of sugars from vegetable fibres during the

setting of the cement can act as a retarding agent for the cement paste [Merzoud 2007]. The extracts of vegetable matters, in fact, consist mainly of hemicellulose polysaccharides which are supposed to delay the setting of the cement paste [Bilba 2003, Peschard 2006, Merzoud 2007 and Sellami 2013]. After that, the treated fibres were dried in oven at a temperature of 70°C until constant mass;

- Both treated and untreated stems were cut with a knife mill *Retsch SM100* operating at 1500rpm using a mesh of 2 mm;
- After cutting, the fibres were water saturated in a container at 25°C and humidity close to 100% R.H. before using them for preparing the mortars. This process allows to obtain a better workability of the mortars without increasing the w/b ratio.

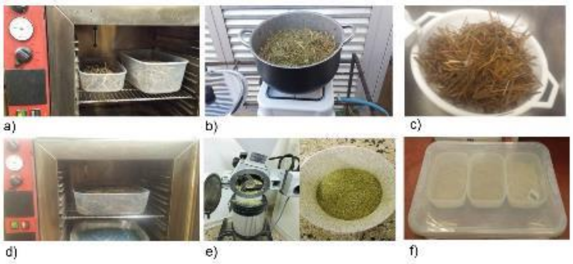

Figure 117: Procedure for the preparation of the fibres (example for boiled Diss fibres): a) drying; b) boiling; c) washing; d) drying; e) cutting; f) water saturation.

2.3 Characterization of the fibres

For both the type of plants, untreated and boiled fibres have been physically and chemically characterized, in order to evaluate the effect of the thermal treatment on the absolute density (helium picnometer analysis), morphology (SEM) and elemental composition (SEM and STA). Furthermore, heat conductivity (heat flow meter test) of the untreated fibres have been evaluated in order to assess the insulating properties of both the type of plants.

Helium picnometry

The real densities of untreated and boiled fibres were evaluated by means of helium picnometry analysis in a *Pycnomatic ATC Thermo Fisher Scientific* picnometer. The values were calculated as the average of at least 8 good measures (maximum standard deviation of 0.05%) in a maximum of 15 test cycles.

SEM

Untreated and boiled fibres have been observed in low vacuum mode in a scanning electron microscope in order to study the morphology of the two species of plants and their modification induced by the thermal treatment. The images have been captured both in SE and BSE mode by setting a High Voltage of 30kV a spot size of 4nm and a nominal working distance of 10mm. Quantitative EDX analysis on the ashes was performed in order to study the elemental composition. In particular, the amount of silicon in the fibres has been evaluated.

Symultaneus thermal analysis (STA)

Simultaneous thermal analysis was performed using the *Netzsch STA 449 Jupiter F1* instrument. The tests were carried out in the 30-1100°C range, with 10°C /min heating rate, 20ml/min nitrogen flux and 40 ml/min air flux.

Heat flow meter test

For the thermal conductivity characterization of the fibres a *LaserComp FOX314 TA-instruments* heat flow meter was used according to the standard ASTM C518. From polystyrene panels of size 300x300x40mm a square cavity of dimensions 150x150x40mm was obtained. It was filled with dried fibres and the panels were wrapped with paper. The values of heat conductivity of the panels were evaluated once reached the steady state of thermal flux between the upper and lower plates set to 25°C and 5°C respectively.

2.4 Preparation of the mortars

Four different types of mortars and the cement paste, used as reference, were prepared. These are defined as follows:

- CEM: Cement paste;
- CEM_30AM: Mortar constituted of binder and 30% by total volume of diss fibres;
- CEM_30BAM: Mortar constituted of binder and 30% by total volume of boiled diss fibres;
- CEM_30PS: Mortar constituted of binder and 30% by total volume of crimson fountaingrass fibres;
- CEM_30BPS: Mortar constituted of binder and 30% by total volume of boiled crimson fountaingrass fibres;

In order to evaluate the proper amount of water for each mixture, the test for the determination of the consistence of fresh mortar (by flow table) has been carried out on a *Controls 63-L0037-E* flow table according to the standard UNI EN1015-3. It was thus calculated the water/binder ratio for every type of mortar, which led to the same workability corresponding to a diameter of flow of the mixture between 13.5 and 14 cm.

For CEM_30AM and CEM_30BAM mortars, the water/binder ratio used was equal to 0.38 while for those CEM_30PS and CEM_30BPS it was 0.40. For the Cement paste it was 0.28.

Three samples for each type of mortar have been prepared by using prismatic steel moulds of dimensions 40x40x160mm according to EN UNI 1015-11 in order to perform the mechanical characterization through three-point bending and compression test. For the thermal characterization, cylinders of 5cm of diameter have been prepared by using cylindrical PVC tubes as moulds. The setting and hardening of the mortars occurred for 7 days within moulds and for 21 days after demoulding in a controlled environment at 21°C and 60% of R.H.

2.5 Characterization of the mortars

Three-point bending test

At least three specimens for each type of mortar were tested according to the standard EN 1015-11 to evaluate the flexural strength at 28 days. Before testing, the actual dimensions (length, thickness and width) of each specimen have been recorded with the aid of a centesimal caliper; the reported measurement was the average of three different measures. Three point bending tests have been performed in displacement control mode in a *Zwick/Roell Z005* testing machine equipped with a 5KN capacity load cell. The crosshead speed was 0.5mm/min in order to cause the rupture of the specimens within 1÷2min.The preload was 20N while the span length was set to 100mm. The flexural strength was calculated using the following Eq. (1)

$$\sigma_b = \frac{3P_{max}L}{2bh^2} \quad (1)$$

where P_{max} is the maximum flexural load, L is the span length, b and h are respectively the width and thickness of the specimen.

Compression test

For each mortar mix, six specimens were tested and the results reported as average and standard deviation of the maximum compression strength obtained from valid tests (at least 5 for each type). The tests were carried out in force control on the halves of the samples previously tested in bending, in a Universal Electromechanical Machine *MP Strumenti Tools WANCE UTM 502*. The loading speed was equal to 200N/s for CEM mortars, 100N/s for CEM_30AM and CEM_30BAM mortars and 50N/s for CEM_30PS and CEM_30BPS in order to cause the rupture of all the specimens within 30s and 90s according to the standard EN 1015-11. A compression jig assembly was used in order to compensate any lack of parallelism between the loaded surfaces of the specimen during compression tests. The compression strength values for each sample were obtained by dividing the maximum load by the resistant cross section of the specimen (40x40mm^2).

Heat flow meter test

Disks between 2cm and 2.5cm of thickness were cut from the cylinders after 28 days of hardening by means of an *IMER COMBI 250 V* water-cooled saw. Before the tests, the samples were dried in oven at 60°C for 24 hours until constant mass, in order to prevent discrepancy of results caused by variable moisture content. Then the specimens have been polished using a *PRESI-Mecapol-2B* polishing machine in order to obtain uniform thermal flow and limited contact thermal resistances. At least three samples for each type of mortar were tested in a *LaserComp FOX 50 TA-instruments* heat flow meter according to ASTM C518 and ISO 8301. The values of thermal conductivity were evaluated through the following Eq. (2):

$$\lambda = \frac{sq}{\Delta T}\left[\frac{W}{mK}\right] \quad (2)$$

where s is the sample thickness, q is the heat flux at the steady state and ΔT is the difference between the upper and lower plates temperature respectively set to 25°C and 15°C. The results were reported as average and standard deviations.

Helium picnometry

After the mechanical tests, fragments from the crushed samples have been analysed by means of helium picnometry in a *Pycnomatic ATC Thermo Fisher Scientific* picnometer in order to evaluate the porosity of the mortars. The values of real density were calculated as the average of at least 8 good measures (maximum standard deviation of 0.05%) in a maximum of 15 test cycles. The porosity of the mortars was obtained by using the following Eq. (3):

$$Porosity\,[\%] = 100\left(1 - \frac{\rho_{app}}{\rho_{real}}\right) \quad (3)$$

where: ρ_{app} is the apparent density, measured as the mass by volume ratio of the prismatic samples before the flexural test, and ρ_{real} is the real density.

3 RESULTS AND DISCUSSIONS

The results of helium picnometry analysis on untreated and boiled fibres (*Fig. 118*) showed that the thermal treatment is supposed to modify the chemical composition of the diss fibres probably due to the removal of sugar and extractives as also stated by Merzoud [2007] and Sellami [2013]. By contrast, no significant changes have been induced by the treatment for crimson fountaingrass fibres.

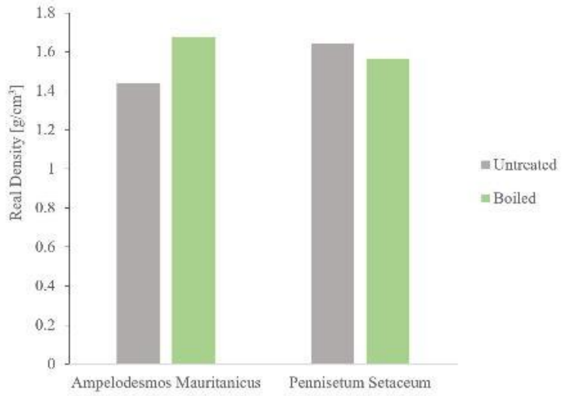

Fig. 118: Density results of untreated and boiled diss and crimson fountaingrass fibres.

SEM image analysis of the two type of plants (*Fig. 119*) evidenced the different surface morphology between diss and crimson fountaingrass fibres. In fact, the former are characterized by the presence of spines, which may promote the adhesion between fibres and cementitious matrix due to better mechanical interlocking, while the latter present a smooth surface. It is also important noting that the thermal treatment does not affect the morphology of the fibres as can be demonstrated by observing the *Fig. 120* that shows the persistence of the spines on the diss fibres surface after the boiling treatment. Quantitative EDX analysis (*Fig. 121*) on the ashes of untreated diss and crimson fountaingrass evidenced the higher content of silicon in the former (approximately 22% by weight) compared to the latter (approximately 9%). This result may signify that diss fibres are characterized by either better mechanical properties or higher reactivity with the cementitious matrix. The latter can be due to the SiO_2 content in the fibres may react with the portlandite present in the matrix to form further calcium silicate hydrates which are responsible for the mechanical properties of the cement. The STA results confirmed those obtained by EDX since the amount of uncombusted was higher for the diss rather than the crimson fountaingrass fibres (*Fig. 122*).

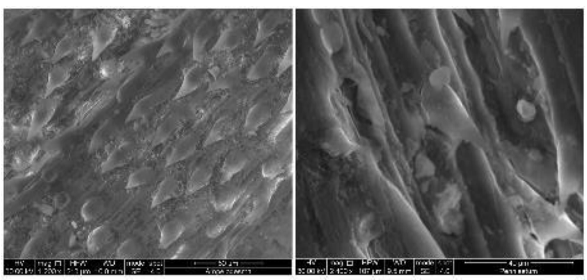

Fig. 119: Comparison between untreated diss (left) and crimson fountaingrass fibres (right).

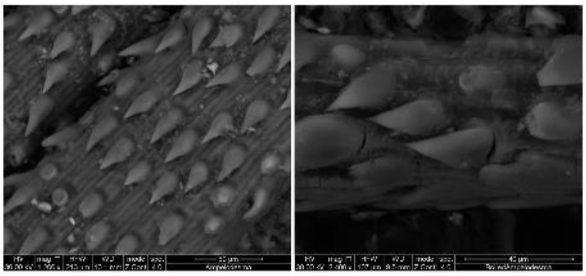

Fig. 120: Comparison between untreated (left) and boiled (right) diss fibres.

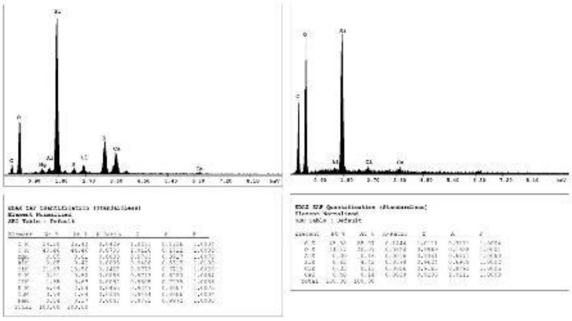

Fig. 121: Comparison of quantitative elemental composition between diss (left) and crimson fountaingrass ashes (right).

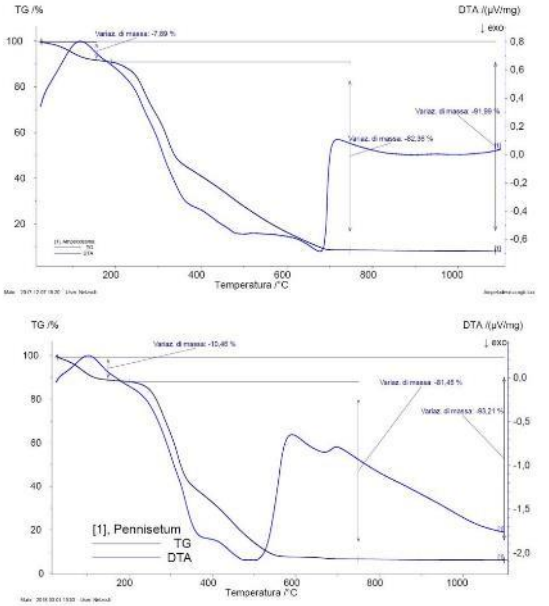

Fig. 122: STA of diss (above) and crimson fountaingrass (below) fibres.

The results of the heat flow meter test of the fibres showed good insulating nature of both the type of plants being the values of thermal conductivity equal to 0.059 W/mK and 0.054W/mK respectively for diss and crimson fountaingrass fibres.

The results of the mechanical tests (*Fig. 123* and *Fig. 124*) on the mortars showed that diss aggregate leads to better performances both in terms of flexural and compression strength compared to crimson fountaingrass one. This can be due to either the better morphology or the chemical composition of the diss compared to the crimson fountaingrass fibres as verified by the results of the fibres characterization. The thermal treatment significantly improves the mechanical properties of the mortars additivated with *Ampelodesmos Mauritanicus* fibres. This can be probably attributed to the chemical modification of the diss fibres (as confirmed by the increase of the real density) which leads to better compatibility between natural fibres and matrix allowing the correct setting and hardening of the cement [Merzoud 2007 and Sellami 2013].

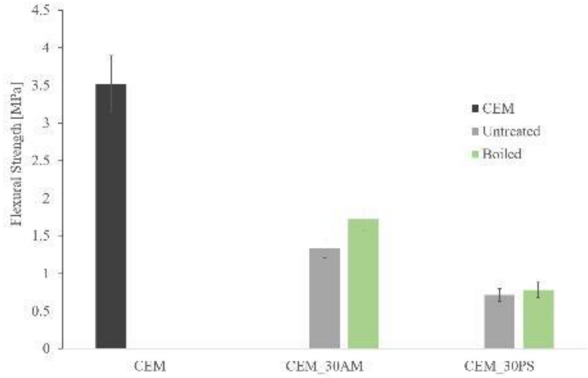

Fig. 123: Three-point bending test results.

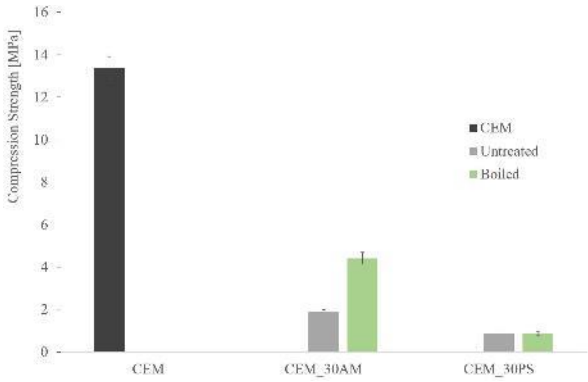

Fig. 124: Compression test results.

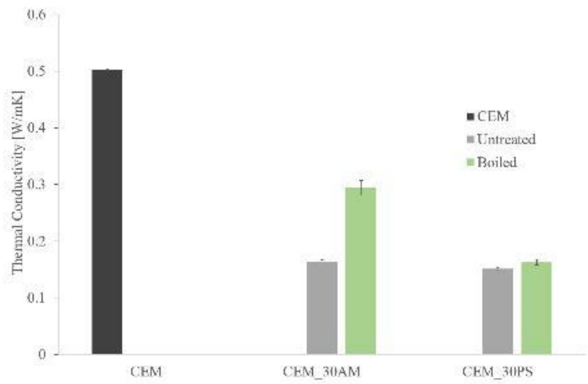

Fig. 125: Heat flow meter test results.

On the other hand, the thermal treatment of diss fibres leads to significantly worse thermal insulating properties, as shown in (*Fig. 125*), compared to the untreated ones. It can be justified either by the lower porosity of the mortars additivated with boiled fibres compared to those additivated with untreated ones (*Fig. 126*) or the increase of the thermal conductivity of the fibres caused by the boiling treatment due to the increase of the real density (*Fig. 118*). Thermal conductivity of CEM_30PS mortar is slightly lower than CEM_30AM probably due to the lower thermal conductivity of the crimson fountaingrass fibres. The thermal treatment does not significantly affect both mechanical and thermal properties of *Pennisetum Setaceum* mortars.

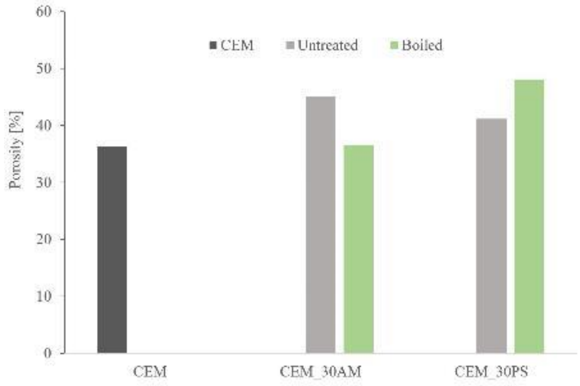

Fig. 126: Helium picnometry results.

4 SUMMARY

In this work two species of plants i.e.: diss (*Ampelodesmos Mauritanicus*) and crimson fountaingrass (*Pennisetum Setaceum*) as aggregate of green concrete have been compared for application as insulating plasters. In particular, the possibility of using the more invasive crimson fountaingrass in place of diss, has been investigated. The characterization of the fibres demonstrated that both from chemical and morphological point of view diss fibres are preferable to crimson fountaingrass as also confirmed by the mechanical results. Although boiling treatment of diss fibres significantly improves flexural and compression strength of the mortar, the effect on the insulating properties is extremely detrimental and may limit their use as aggregate for insulating plasters. In future works further physical and chemical treatments on *Pennisetum Setaceum* will be investigated in order to improve the compatibility with the cement matrix and promote their use in place of diss for green concretes.

5 ACKNOWLEDGMENTS

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