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Elaboration of a Lignocellulosic Composite Formulated with a Local Resource: Diss as Infill in Structures Submitted to Seismic Actions

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Abstract: The Diss (*Ampelodesmos mauritanicus*, family of Poaceae) is a very luxuriant plant growing in wild state around the Mediterranean North Africa and dry areas of Greece and Spain. It grows in France, mainly, in the departments of the Alpes-Maritimes, the Var, the South of Corsica and Herault. In the past, it was used as building material because of its mechanical and hydrous qualities. The use of such a fibrous plant in a cementitious matrix leads to lightweight materials with very attractive tensile behavior that can be used as advantageous filling materials for structures subjected to seismic effects. This study is focused on the optimisation of this kind of material on the basis of mechanical properties. The basic vegetable material, very fibrous and siliceous, presents indeed an absorption of about 90% that would be corrected. Moreover, we noted a considerable retardation of setting and very low resistances during the composite tests with natural crushed diss, despite the fact that the fibres have considerable tensile strength. To improve the fibres contribution in cementitious composites, we have carried out a treatment by boiling the fibres of diss to extract the substances responsible for the bad connection between fibres and the cement paste. The results obtained are encouraging and enable to foresee a later development of this material.

Key words: Lignocellulosic Diss, ampelodesma mauritanica, fibres, infill, seismic

INTRODUCTION

Concrete containing lignocellulosic materials has been, in the last decades, subjected to numerous interesting research works. Indeed the vegetable matter represents a source of renewable products.

Demirbas and Aslan (1998) showed that the addition of lignocellulosic elements like the ground hazelnut shell, wood and waste of tea is negative on the mechanical properties of cement. They showed that the compressive strengths and to the inflection decrease with the increase in the proportions of these mixtures. The experimental results showed that the lignocellulosic material specimen cannot be used like composite in the industry of the concrete. The hazelnut shells and the back wood can be used like partial or additive replacement with Portland cement. On the other hand the use of waste of tea like addition or aggregate is never allowed.

Asasutjarit *et al*. (2007) used residues of coconut coir as aggregate in lightweight Cements Boards (CCB). It was concluded about this research, that for the production of coconut coir cement boards, it's required to boil and wash the coir and this pretreatment enhanced some of the physical and mechanical properties of coir fibres.

Savastano *et al*. (2000) used residues of sisal, banana tree and eucalyptus as reinforcement in cementing composites. The composites thus obtained present acceptable mechanical performance. The studies of Kriker *et al*. (2005) based on the use of four types of date palm fibres in a cementitious matrix, showed that the increase of length and percentage of fibres improves the flexural strength and hardness of the composite, but decreases the compressive strength. The use of banana tree, sugar cane and coconut fibres, as epoxy polymer concrete reinforcement (Reis, 2005) shows that the coconut fiber, unlike the two other types of fibres, makes it possible to obtain a slight increase of the composite flexure. Ledhem *et al*. (2000) showed in their research on cementitious composites containing wood shavings that the thermal treatment of wood could increase the mechanical resistance, thermal conductivity and reduce extreme dimensional variations of the composites. Aamar (2004) used dust from the stripping of flax fibres as aggregate in a composite with cementing matrix. His works showed that the treatment of flax dust with boiled water improves considerably the mechanical resistance of the composites.

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Fig. 1: Diss Plant (ampelodesma mauritanica)

Fig. 2: Stems of Diss

The strongly alkaline environment developed by the hydration of cement causes hydrolysis reactions and solubilises some compounds, as sugars, hemicelluloses and pectins (Simatupang, 1986). Garci and Jennings (2002) and Bilba *et al.* (2003) have studied the influence of sugars on the setting of the cementitious composites and showed that sugar retards cement hydration. The existing literature concerning diss fibres seems to indicate that there is a lack of technological valorisation of this plant, Fig. 1 and 2 in particular in the field of cementitious composites. This plant species exists in wild state and in large quantity around the Mediterranean countries and its fibrous nature seems to offer as much qualities to the cementitious composites as the traditional fibres. However many studies (Vila *et al.*, 2001) reported a great oil accumulation in the vegetable matter, which is likely to interact with the cementing paste. This is why further treatments must be carried out.

In order to reduce the water absorption of this plant, which is about 90% and the retardation of setting observed during the mechanical tests on composites containing crushed natural Diss (Fig. 3) we have carried a treatment of fibres: by boiling (extraction of the soluble substances).

Fig. 3: Crushed natural Diss fibres

MATERIALS AND METHODS

Materials: The diss material as aggregate in our composites, has been crushed with a 10 mm mesh Retsch type cutting mill. The different stages of study of crushed diss fibres are as follows:

- Tr1: fibres of natural diss, dried in the oven at 50 and 100°C
- Tr2: fibres boiled in water, then dried in the oven at 50°C

During the treatment with boiling water, we have preserved the boiled water residue to study its influence on the setting of cement (Fig. 4).

The cement used was a CPA type CEMI 52.5 (standard EN 196-1).

Experimental methods: The morphology of various fibres was studied by Scanning Electron Micrographs (SEM).

The images have been taken with the following devices:

- Video microscope (Controlab®) VH-Z25 provided with a zoom 25 to 175x,
- An annular light with cold lighting appliance, nondiffuse lighting, semi-shaving, positioned on the video microscope, allowing the description of the relief of the samples,
- A high resolution screen 507×688 pixels,
- A PC,
- A system of vision VIDEOMET (Controlab®) allowing digitalisation and visualisation of images.

Fig. 4: Boiled crushed Diss fibres

The test specimens made with various fibres, treated or not, are preserved during 28 days in a storage room (R.H = 95%, t = 20°C) and then dried at 50°C until a constant mass before testing (Fig. 5).

Mechanical tests were carried out, according to the European standard EN 196-1, on prismatic specimens 4x4x16 cm. The tensile strengths were measured using a three points flexural test bench, equipped with a system of acquisition. The compression tests were carried out on the half retained from flexural testing, with a standard machine Perrier 68.7.

The dynamic elastic modulus was determined by sonic method, standard E0641 Ultrasonic Tester, on prismatic specimens 4×4×16 cm. The principle is based on the determination of the propagation velocity of the ultrasonic waves (celerity) in the composite. The dynamic elastic modulus is given by the relation:

$$Ed = \rho C_L^2 \quad (1)$$

With Ed = dynamic elastic modulus (MPa), ρ = Bulk density of the specimen (kg m^{-3}), C_L = celerity of wave (m s^{-1})

Formulations: The systematic study of mechanical strength according to the Water/Cement ratio (W/C), allowed to choose, for each type of fibres, the W/C ratio corresponding to optimal compressive and flexural strength of composites. During this work, the W/C ratio was varied between 0.5 and 0.9.

The Diss fibres/cement ratio was set to 4:1 (by volume) for all formulations.

The obtained experimental results for boiled diss composites are shown on Fig. 6.

Table 1 summarises the obtained experimental results of water absorption percentage and the optimum W/C ratio for various treatments applied to fibres.

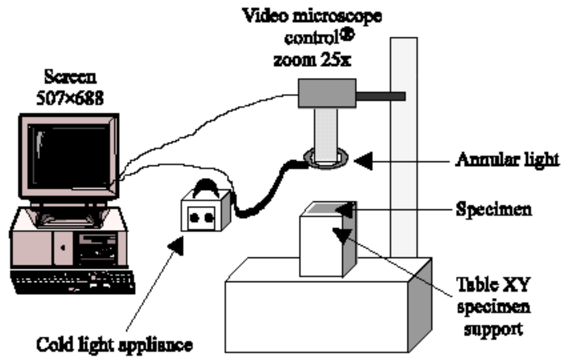

Fig. 5: Images analysis test setup

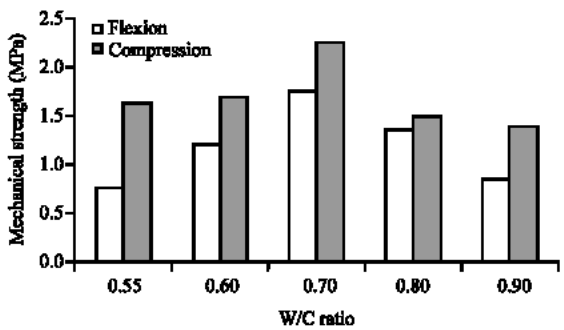

Fig. 6: Mechanical strength (in flexion and compression) versus W/C for various formulations of boiled diss

Table 1: Water absoption percentage and the optimum W/C ratio for various treatments applied to diss fibres

Vegetable fibres	% Water absorption	Optimal W/C
Tr1	92.38	0.7
Tr2	90.00	0.7

RESULTS AND DISCUSSION

Dynamic elastic modulus: The average values obtained during this research for the dynamic elastic modulus and bulk density are represented in Fig. 7 for various formulations.

It can be observed that for the same bulk, the dynamic elastic modulus values are very low for the untreated diss fibre composites. This can be attributed to the absence of diss fibres adherence to the cement paste because of the bad cement hydration. The most important values were obtained for the boiled and washed diss coated, because of the fibres strong adhesion to the cementing matrix. It was found that 2 h of boiling in water was sufficient to reduce water soluble chemicals such as sugar, starch, resin and phenols. Then diss fibers must be washed with abundant tap water until the color of water became clear.

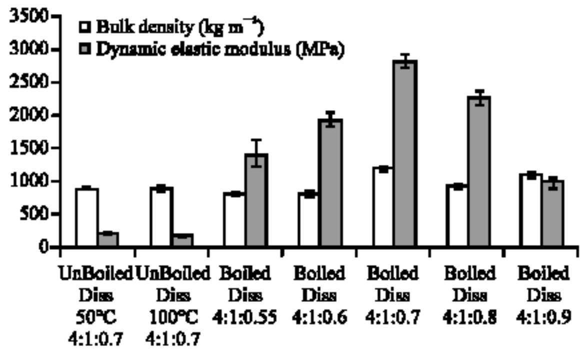

Fig. 7: Dynamic elastic modulus and bulk densities for various treatments

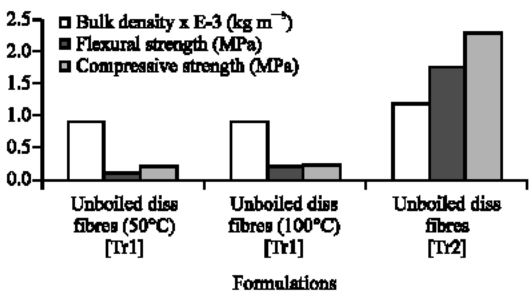

Fig. 8: Mechanical strength and bulk densities for various treatments

Mechanical strengths: The average mechanical strength in compression and flexion and bulk densities of various composites are represented in Fig. 8 for various formulations.

Case of untreated vegetable fibres: The mechanical strength results of composites containing unboiled diss dried in the oven at 50 or 100°C remain very low (Fig. 9). This phenomenon is certainly due to exchanges occurring at the matrix-fibres interface and the hydrolysis and solubilisation reactions of some compounds such as sugars, hemicelluloses and pectins caused by the highly alkaline environment developed by cement hydration. The presence of these soluble fractions was also confirmed by adsorption tests in vapor phase of diss fibres (Fig. 10 and 11). During these tests, some mould appeared on unboiled diss fibres at the end of the eleventh day, whereas no development was noted in boiled diss fibres during all test periods. It can be noted that water-soluble fractions evaluated at 16.83 % are the cause of weak adhesion of materials (Fig. 12).

Influence of hydrothermal treatment: Boiling treatment: In accordance with the results obtained by Demirbas,

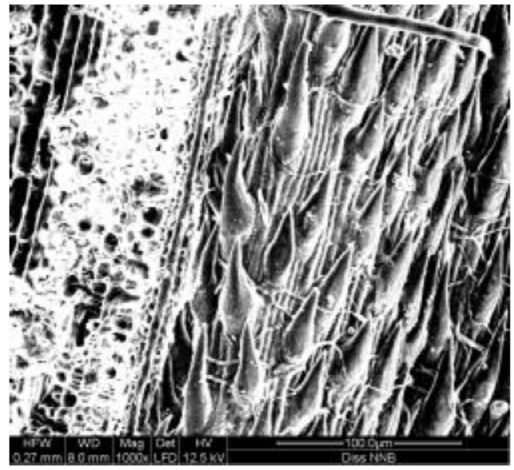

Fig. 9: Scanning electron micrographs of unboiled diss fibres, magnification×1000

Fig. 10: Unboiled diss composite specimen after flexural test

Fig. 11: Unboiled diss composite specimen after compression test

Aslan (1998) and Ledhem *et al.* (2000) and Aamar Daya (2004), the boiling treatment of diss fibres in the treatment water allows to eliminate soluble matters, which are the

Table 2: Tests of initial setting time with various mixing waters

Sample	Initial setting time (h)	Final setting time (h)
Cement + Water of the network	4.50	6.00
Cement + Water residue of the boiled diss	8.00	16.00

Fig. 12: Video microscope image on the crack of unboiled diss composites, magnification×25

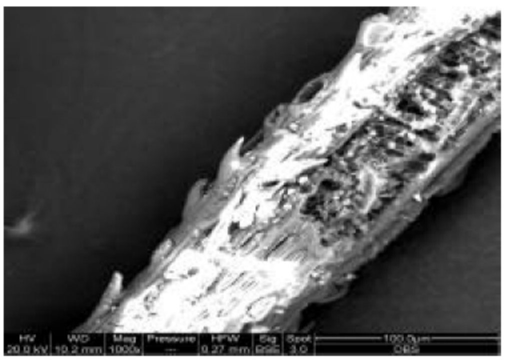

Fig. 13: Scanning electron micrographs of boiled diss fibres, magnification×1000

cause of retardation of setting and lack of cohesion between aggregate and matrix. Indeed the use of water treatment in the cement paste has showed an important initial retardation of setting. The results are summarized in Table 2.

Strong strengths are of course due to the elimination of the detrimental substances, but it is also necessary to point out to the influence of the diss fibres skin. Indeed the skin of diss fibres is composed of tiny spines which will allow a better adhesion to the cement paste as shown on Fig. 13. This type of fibres/matrix cohesion offers better tensile strength in flexural tests and better lateral tension in compressive tests.

The high strength of these composites is also due to the fact that the fibres are placed longitudinally, which enables them to adhere well to the cement paste and

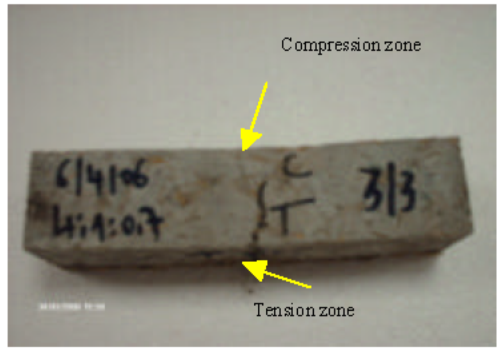

Fig. 14: Boiled diss composite, W/C=0.7 ratio, after flexural test

Fig. 15: Video microscope image on the crack, magnification×50

Fig. 16: Detail of fibre of figure 15 surrounded in red, magnification×175

behave as reinforcement (Fig. 14). Moreover, at the flexural crack level at the tensional section, we noted that the diss fibres are well coated in packages by the cement paste, which enables them to resist well to the tensile stress. (Fig. 15 and 16).

CONCLUSION

This research related to the optimization of a cementing composite containing Boiled and washed Diss. It clearly appears that boiling water treatment improves the performance of the composite thanks to the elimination of the water-soluble compounds evaluated for unboiled diss at 16.83% and for boiled and washed diss at 4.95%. Moreover, the fibres are placed longitudinally and in parallel, which tends to increase their role of reinforcement.

The boiled diss composites have considerably resisted at the tensile stress in flexural tests without appearance of cracks at the first loading stages. In compression, these boiled diss composites have not shown any crack and the specimen remained undamaged. While the unboiled diss composites did not appear any resistance in flexion and in compression.

The treatments in boiled water have improved the mechanical characteristics of the composites, while the structure of fibres did not change. The fibres are placed longitudinally in the composites, which offer them the ability as reinforcement, without increasing the bulk densities which vary from 800 to 1200 kg m^{-3}.

Because of their lightness and their ductility behaviour, these composites can be used as infill in the structures subjected to the seismic efforts.

The improvements caused by the presence of boiled diss fibres in the composites are due to:

- The adherent capacity of the fibres to the cement paste, caused by their thorny structures;
- The better tensile strength, caused by the formation of package by the cement paste;
- Their fine structure favourable to the longitudinal fibres disposition in the composites and offer them the ability to improve the mechanical strength.

The optimum composite composition in term of volume of diss fibres: Cement: Water ratio is therefore 4:1:0.7.

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