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Properties of construction material based-Diss fibers: Physico-mechanical characterisation

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Abstract. In the building sector, issues related to sustainable development have become a major concern. The choice of materials has fundamental importance since it has a considerable influence on the energy consumption of the building and also on the overall environmental impact of the construction. Materials reinforced with vegetable fibres and/or particles are currently considered amongst the most promising materials in sustainable engineering technologies due to their several potential applications. In addition to its sustainable credentials, the application of these elements is interesting as they exhibit a set of important advantages, such as wide availability at relatively low cost, bio-renewability, ability to be recycled, biodegradability, non-hazardous nature, zero carbon footprint, and interesting hygro-thermal and mechanical properties.

The viability of using vegetable Diss fibers for developing a sustainable lightweight construction material was investigated in this paper. The produced specimen contained 4/1 volume ratio of Diss fibers to Binder. In order to mitigate the inhibitory effect exerted by vegetable materials on binder hydration, Diss fibers were treated with hot water, while air lime-based Tradical PF70 binder has been selected to replace traditionally used cementitious binder. The study conducted on hardened material properties has indicated that despite a significant reduction in mechanical strength, the material exhibits higher residual stress that highlighted a ductile behaviour, compared to the reference specimen containing neat binder without Diss fibers.

Key words: Diss fibers, Composite, Physico-Mechanical Properties, Ductility, Brittleness Index.

1. Introduction

In recent years, the building sector has been marked by a general awareness of the need to limit the impact of the materials used on the environment. To achieve this objective, both economic and environmental restrictions should be taken in consideration, which encourage the integration of the "sustainable development" concept in the choice of materials. In this context, the building sector must therefore work to convert its constructive practices and to offer innovative materials that meet the new requirements of users and legislation in terms of environmental and health impact, and comfort. In this context, innovative building solutions for conserving non-renewable resources have motivated extensive research to develop sustainable building materials based on easily renewable natural raw material resources. There is a growing interest in the utilisation of vegetable materials as aggregates and/or fibers reinforcement into lightweight composites called "green" composites/concretes for sustainable constructions. However, various types of vegetable wastes (flax, hemp, coir, jute, bamboo, palm, kenaf, diss…), after being processed, have been used in particles form as replacement of sand and aggregates in concrete and mortars (Elfordy et *al*., (2008), Gavrilescu et *al*., (2009), Pereira et *al*., (2019), Sassoni et *al*., (2014). Due to their many advantageous properties as their eco-friendly and economical characteristics, vegetable materials can adequately replace mineral aggregates in construction field. These materials exhibit a high insulation capacity associated to a low density, and provide healthy living solutions, thanks to the vegetable materials ability to regulate humidity inside buildings by absorbing and/or releasing water, depending on the air conditions (Ardanuy et *al*., (2015), Barra et *al*., (2012).

Although all the mentioned advantages, the production of specimen materials reinforced with vegetable particles is limited by their long-term durability. The degradation problem is associated with an increase in vegetable materials fracture due to a combination of their weakening by alkali attack, related to their both mineralization and high-water absorption (Ruth & Ranyl, (2010), De Bruijn et *al*., (2009). This causes the material to have a reduction in post-cracking strength and toughness. The role of vegetable materials as reinforcement lies in the proper interfacial bond between the particles and the matrix as well as to ensure the durability of the specimen. To enhance the performances of vegetable particles, several approaches have been studied including particles impregnation with blocking agent and water-repellent agent, sealing of the matrix pores system, reduction of the matrix alkalinity, and combination of particles impregnation and matrix modification (Karade, (2010), Mohr et *al*., (2005), Daher et *al*., (2018).

The main objective of this work was to investigate the potential use of Diss fibres as reinforcement additives in Tradical PF70 hydraulic binder, within the scope of providing an alternative solution to an environmental approach. The diss fibres are added at a volume ratio of 4:1 to preformulated Tradical PF70based-binder. In order to mitigate the inhibitory effect exerted by vegetable particles on hydration reaction of binder, due alkali-dissolved components, the Diss fibers were treated with hot water. The effect of Diss fibers has been assessed by means of mechanical properties, such as compressive and flexural strengths, cracking behavior, and brittleness Index.

2. Materials and experimental testing

2.1. Materials and specimen production

The binder used in this study consists of a preformulated mixture of 75% air lime, 10% hydraulic lime, and 15% of pozzolan, and called "Tradical PF70". The binder material is produced by Lhoist industry (BCB, (2015), which is located in the Northern region of France.

The Diss (Ampélodesmos Mauritanicus, from poaceae family) is a very widespread grass in North Africa and the dry regions of Greece to Spain. Because of its fibrous nature, Diss fibers contain a high amount of silica in the amorphous state, which highlight a high tensile strength. In order to overcome the inhibitory effect excreted on hydraulic binder, the Diss fibers were boiled with hot water to ensure the dissolved components partial extraction that affect the hydration reaction of binder. After treatment, the Diss fibers were dried in an oven drying, converted into fibers and then sieved with a maximum length of 1 cm. Figure 1 shows the shapes of natural plant of Diss and derived fibers after drying and crushing. The properties of treated Diss fibers are listed in Table 1.

Table 1. Properties of treated Diss fibers

Bulk density (kg/m^3)	Absolute density (kg/m^3)	Porosity (%)	Water absorption (%)
47	1380.5	97	290

Fig. 1. Shape of plant (a) and derived treated Diss fibers (b)

The control specimen consists of a neat binder without Diss fibers, with total mixing water to binder ratio of 0.6. Tradical binder and mixing water were initially mixed for 2 minutes in a planetary mixer. The vegetable Diss fibers were then uniformly dispersed with slow increment throughout the binder and the fresh materials were allowed to mix for three additional minutes. At the end of this stage, the fresh material was cast into cylindrical (110 x 220 mm) and prismatic (40 x 40 x 160 mm) samples. All specimens were well compacted on a vibrating table and moist-cured for 28-days at 20 ± 2 °C and 98 % relative humidity, before testing. The specimen mixes and their designations are shown in Table 2.

Table 2. Composition-mixes and I.D of specimens

Material	Specimen-ID	
	TS [1]	TDS [2]
Tradical binder (m^3)	1	0
Diss fibers (m^3)	1	4
Water/Binder ratio (in mass)	0.6	0.7

[1] Control Specimen (Neat Tradical binder) ; [2] Tradical Diss Specimen (with 4 volumes of Diss fibers)

2.2. Experimental testing

The 28-days properties tested on the hardened specimens included dry unit weight, as determined by means geometrical measurement and weighting. The compressive and flexural strength-tests were conducted according to the European Standard EN 196-1 (AFNOR, (1995)). The compressive strength-tests were carried out on (110 x 220 mm) cylindrical samples, using an electromechanical testing machine SHIMADZU AG-IC model with a maximum load capacity of 250 kN and a constant rate of 4 mm/min (Fig. 2a). The compressive stress-strain diagrams were recorded to evaluate the variation of ultimate strain, elastic modulus, and ductile and/or brittle nature of the specimens. The three-point bending flexural-tests are performed on (40 x 40 x 160 mm) prismatic samples. The electromechanical testing machine TINIUS OLSEN H50KS type was used with a load cell capacity of 50 kN and 0.4 mm/min of loading rate (Fig. 2b).

The load-deflection diagrams were recorded to evaluate several parameters such us flexural strength, ultimate deflection at peak load, elastic modulus of rupture, and ductile and/or brittle nature of the specimens through the Brittleness Index (*IB*), as evaluated by Eq. 1. The correspondent schematic diagram of load-deflection is shown in Fig. 3 (Consoli et *al*., (2002). If (*IB*) tends to 1, the specimen is brittle, while (*IB*) tends to 0, the specimen exhibited a ductile behavior.

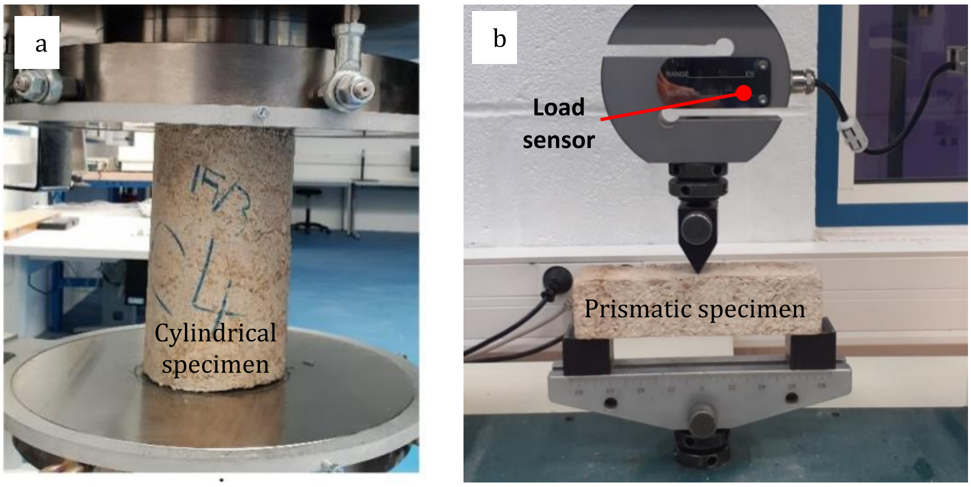
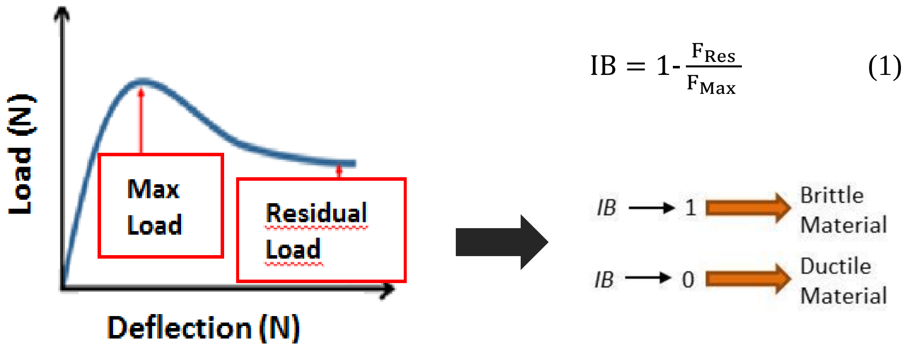


Fig. 2. Mechanical-test machines. (a): Compressive-test ; (b): Flexural-test



$$IB = 1-\frac{F_{Res}}{F_{Max}} \quad (1)$$

Fig. 3. Brittleness Index-value determination

3. Results and discussion

3.1. Compressive strength of reinforced specimens

The 28-days stress-strain curves of specimens are shown in Fig. 4. The results indicated that the addition of Diss fibers serves to decrease compressive strength from 6.7 MPa, for Control Specimen, to 2.8 MPa for specimen containing Diss fibers. It corresponds to reduction of approximately 58 %. The decrease in strength is related to the mechanical properties of Diss materials since they are less stiff than the surrounding hydraulic binder. The roughness surface of fibers may be the important limiting factor that leads to interfacial bond defects between particles and matrix. It is assumed that mechanical strength of specimen is opposite to its unit weight. In addition, the decrease in compressive strength is related to porous structure of specimen.

The 28-days parameter-values derived from compressive-test are shown in Table 3. The corresponding elastic modulus-value varied from 962 to 57.2 MPa when Diss fibers were added. However, the results also highlighted the ductile failure of the specimen-based Diss materials that exhibits high plastic phase and underwent significant displacement before fracture. The correspondent ultimate strain-value varied from 7.22 mm/m, for control specimen, to 145.21 mm/m for TDS sample. Fig. 5 shows the failure shape of Diss fibers-reinforced specimen after ultimate fracture. It indicates a large difference in ductility between the control specimen (TS) which exhibited a brittle failure and shattered into small pieces, when it reached the peak load. The addition of Diss fibers changes the brittle behavior while the specimen experienced a more ductile failure. However, the specimen was able to sustain loads after reaching its ultimate capacity. In addition, a high packing in the area subjected to loading has been observed.

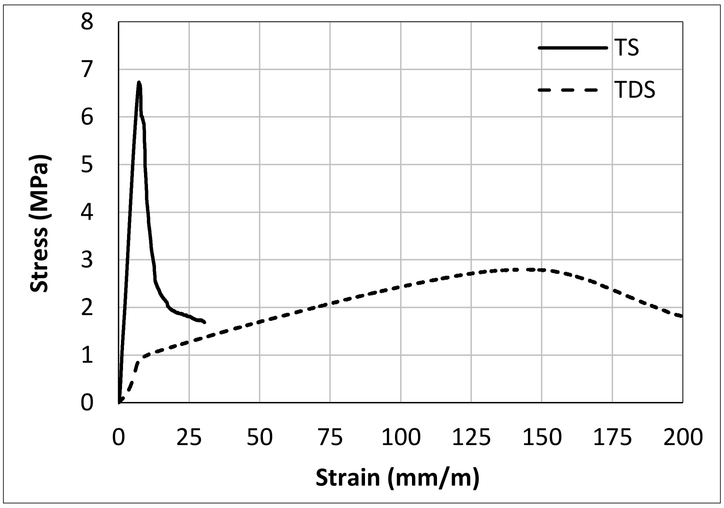


Fig. 4. Stress-Strain diagram of specimens under compressive test

Table 3. 28-days parameter-values of specimens under compressive test

Specimen-ID	Compressive strength (MPa)	Ultimate strain (mm/m)	Elastic modulus (MPa)
TS	6.7 ± 0.2	7.22 ± 1.0	962.0 ± 10
TDS	2.8 ± 0.4	145.21 ± 10	57.2 ± 15

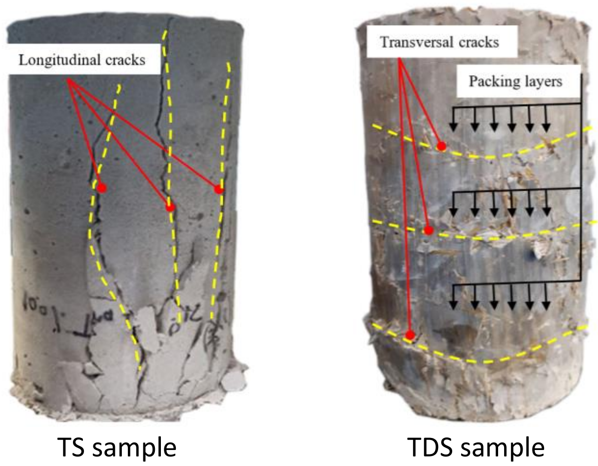


Fig. 5. Specimen shapes after failure under compressive-test

3.2. Flexural strength of reinforced specimens

The 28-days load-deflection response of specimens submitted to flexural-test is shown in Fig. 6. A reduction in flexural strength was observed when Diss fibers were added. Value decreased from 1 MPa, for reference specimen (TS), to 1.05 MPa for TDS sample with 4 volumes of vegetable fibers. The value corresponds to reduction of up to approximately 50 %. This finding suggests that both mechanical properties of vegetable materials and sample's porous structure lead to decrease the mechanical strengths of specimen. Results also indicated that the decrease in flexural strength is lower than that observed in compressive strength, probably due to the dilution effect of Diss fibers.It is considered that the tension effect of the fibers occurs during the diffuse micro-cracking phase of "bending" the active micro-cracks and then in delaying the onset of their appearance, which serves to improve material flexibility. This could also explained by the capability of fibers to bridge the cracks and lead to limit their progression in the matrix. This bridging effect makes the Diss reinforcement specimen ductile behavior which exhibited Brittleness Index *IB*-value of 0.4, while control specimen showed a value of 1. The corresponding parameters, reported in Table 4, show an increase in deflection with Diss fibers addition. The variation of elastic modulus confirmed this tendency with decreasing the corresponding value. Fig. 7 shows the shape of specimens after failure under flexion-test. The bridging action of Diss fibers during the flexural loading for TDS sample was observed. Unlike the control specimen, the reinforced sample retains its structure and the crack lips remain linked by the fibers. The presence of fibers allows the better control of cracks propagation which thus results in delaying of the rupture phase.

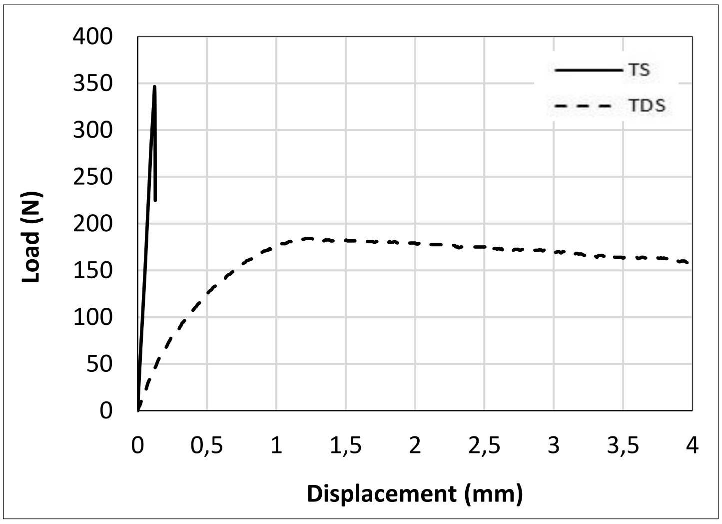


Fig. 6. Load-Deflection diagram of specimens under flexural test

Table 4. 28-days parameter-values of specimens under flexural test

Specimen-ID	Specimen-ID	
	TS	TDS
Max. Load (N)	346 ± 15	184 ± 20
Residual Load (N)	0.0 ± 0.2	107.5 ± 20
Max. Stress (MPa)	1.05 ± 0.1	0.52 ± 0.2
Ultimate deflection (mm)	0.13 ± 0.06	1.23 ± 0.12
Elastic modulus (MPa)	485 ± 10	30 ± 12
Brittleness Index IB	1.00 ± 0.1	0.41 ± 0.12

Fig. 7. Shapes of specimens after flexural failure

4. Conclusions

In this study, experiments have been performed to investigate the feasibility and mechanical properties of Diss fibers reinforced specimen, using Tradical PF70 binder, as other traditionally binders replacement to such as cement, lime, clay.... The procedure has been conducted throughout compressive/flexural strengths, and the examination of elasticity behavior. These properties are also compared with those obtained with specimen without Diss fibers addition.

Tests performed on hardened specimen have shown that the use of Diss fibers reinforcement induced significant reduction in mechanical strengths. Although the loss in the compressive-strength which attained 58%, the reinforced specimen satisfies the basic requirement for load-bearing wall, according to the RILEM classification (RILEM LC2., (1978). However, the decrease in flexural strength is less important than to the compressive strength. This may be due to the dilution effect that leads to limit the progression of the cracks in the matrix, derived from the bridging phenomena. Results also highlight the ductile failure of Diss fibers reinforced specimen which exhibits high plastic phase and underwent significant displacement before fracture.

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