Optimisation of the mechanical properties of Miscanthus lightweight concrete

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Abstract –In this paper, Miscanthus fibres are used to develop lightweight concrete. The amount of Miscanthus and cement, as well as the water/cement ratio, are varied to analyse the behaviour of the mixture concerning the physical and mechanical properties. The Miscanthus was pre-treated with a silicate sealant or a cement-based fluid. The current paper analyses the impact of the pre-treatment of the Miscanthus fibres on the compressive strength as well as on the long-term deformations. The specimens with a pre-treatment based on a silicate sealant reached a compressive strength of 19.3 MPa, which is higher than the compressive strength of a conventional LC 16/18, a Young's Modulus above 9.9 GPa and a shrinkage deformation of 2244 $\mu m/m$. Nevertheless, considering the density the pre-treatment showed not to be beneficial.

Keywords – Miscanthus x giganteus; Miscanthus lightweight concrete; Pre-treatment of Miscanthus fibres; Compressive strength; Shrinkage.

1 INTRODUCTION

The replacement of aggregates by Miscanthus in concrete formulations aims to reduce the depletion of natural resources such as natural sand and gravel, which are continuously diminishing at some regions of the world due to significant exploitation [1]. This scarcity of natural resources is especially visible in highly developed countries, where opening new quarries become more problematic due to strict governmental regulations. In addition, the use of the Miscanthus plant is a sustainable solution as this plant is among others cultivated for depolluation of industrial wasteland.

The Miscanthus x giganteus (Mxg) plant originates from tropical and subtropical regions [2], and its first cultivation in Europe was in the 1930s. Since 1989, field trials have been performed with this plant to investigate its biomass potential. This plant can grow up to 4 m, and the low need for fertilisation and pesticide inputs makes this grass economically and ecologically very interesting. Moreover, this plant decreases water pollution on soil organisms and increases its fertility [3]. These advantages, in addition to the positive impact on biodiversity, render phytoremediation of industrial soils possible. However, during the first winter, the plant presents a narrow genetic base and a low firmness [2]. In the following years, the plant can develop a considerable growth and can achieve a mass production of about 10 to 30 t dry weight per ha per year, considering European climatic conditions and still depending on the different regions [4, 5].

The cross-section of Miscanthus is composed of four types of tissue layers and is subdivided into three regions (**Fig. 1**). The outer zone comprises the epidermis (Ep), the sclerenchyma (Sc) and small vascular bundles (Vb). Ep represents the protective outer coating of the cross-section. Sc embodies the outer cell ring, which supports the structural framework of the plant. The Vb consist of supportive and protective tissues and are heterogeneously distributed over the whole cross-section. The intermediate zone is composed of vascular bundles and parenchyma (Pa). The inner region mostly accommodates parenchyma tissues, which are mainly responsible for the photosynthesis process and the commutation of gases [6, 7].

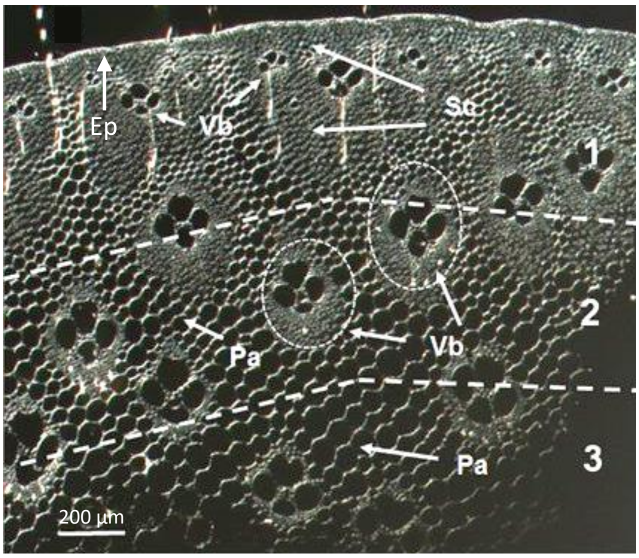

Fig. 1: Cross-section of a Miscanthus x giganteus stalk (adapted from B. Chabbert et al. [6])

Ep = epidermis, Sc = sclerenchyma ring (outer ring), Vb = vascular bundles and Pa = parenchyma ring

Nowadays, the use of natural fibres is continuously increasing. The C4-plant Mxg is, e.g. used for energy and biofuel production [8] or as deep litter bedding for horses on account of their high water absorption capacity (in average 304 % [9, 10]). Also, the trend of using natural fibres for lightweight concrete (LC) has grown [11]. Therefore, investigations are carried out on bamboo, jute, flax, hemp, Miscanthus and wood fibres to develop renewable construction materials [12-22].

K. Kaack et al. [23] determined the material properties of Miscanthus stems including the flexural rigidity (1-3.5 Nm^2), the moment of inertia (18 000-35 000 m^4) and the Young's Modulus (2-8 GPa). They concluded that the mechanical characteristics mostly depend on the number of subdivisions of the primary stem (internodes) [23]. For comparison to the Young's Modulus of Miscanthus with other natural fibres, O. Faruk et al. [24] analysed the Young's Modulus of bamboo (11-17 GPa), jute (26.5 GPa), flax (27.6 GPa) and hemp (70 GPa) fibres.

Concrete mixtures based on lightweight aggregates are conceived using different binders and component variations. H. Ramaswamy et al. [25] constituted mixtures based on jute, coir and bamboo fibres using weight proportions of 1:3.58:2.87 (cement:sand:coarse aggregate), a w/c ratio of 0.65 and 1% (in vol.) of fibres. After a curing time of 28 days, a compressive strength of 6.86 MPa (jute), 8.33 MPa (bamboo) and 10.3 MPa (coir) have been achieved. Furthermore, an LC based on hemp fibres, with a fibre length of 7-8 mm, was investigated by L. Arnaud and E. Gourlay [26]. They analysed the impact of four hydraulic limes on the compressive strength (**Table 1** (A1 – A4)). The investigated binders were NHL 3.5 (Mix A1), NHL 3.5 Z (Mix A2), NHL 2 (Mix A3) and a pre-formulated lime-based binder based on air lime (75%), hydraulic lime (15%) and pozzolanic lime (10%) (Mix A4). In addition to these variations, the effect of different curing conditions was examined by alternating the relative humidity (RH) of the environment (RH = 30%, 50%, 75% and 98%). The highest compressive strength was reached by the specimens cured in an atmosphere of 20°C and an RH of 50% (**Table 1** (A1 – A4)). L. Arnaud and E. Gourlay [26] state that a higher RH (75 and 98%) had with a reduction of 45-55% a negative impact on the compressive strength due to the impediment of carbon dioxide diffusion from the binder. From these four limes, the mixtures using NHL 3.5 and the pre-formulated binder showed the highest compressive strength (**Table 1** (A2, A4)). C. Niyigena et al. [19] analysed different types of hemp shives and achieved similar compressive strength (0.13 – 1.07 MPa) as L. Arnaud and E. Gourlay [26].

Lit.			Aggregate	Cement	Lime	Water	

	Mix name	Lightweight aggregate type	[kg/m³]	[wt.%]	[kg/m³]	[wt.%]	[kg/m³]	[wt.%]	[kg/m³]	[wt.%]	Compr. strength [MPa]
[25]	-	Jute	n.g.		n.g.		n.g.		n.g.		6.86
	-	Bamboo	n.g.		n.g.		n.g.		n.g.		8.43
	-	Coir	n.g.		n.g.		n.g.		n.g.		10.3
[26]	A1	Hemp shives	n.g.	14.3	n.g.	-	n.g.	34.8	n.g.	50.9	0.18
	A2	Hemp shives	n.g.	15.4	n.g.	-	n.g.	37.7	n.g.	46.9	0.31
	A3	Hemp shives	n.g.	15.9	n.g.	-	n.g.	38.9	n.g.	45.2	0.22
	A4	Hemp shives	n.g.	14.3	n.g.	-	n.g.	34.8	n.g.	50.9	0.33
[27]	B1	Hemp shives	n.g.	16.0	n.g.	-	n.g.	34.0	n.g.	50.0	0.18 – 0.85
[28]	C1	Sawdust 75% waste paper	n.g.		n.g.		n.g.		n.g.		0.80
[29]	D1	Hemp composition	n.g.	12.0*	n.g.	-	n.g.	42.7*	n.g.	45.3*	0.20(1)
	D2		n.g.	12.4*	n.g.	-	n.g.	37.6*	n.g.	50.0*	0.15(1)
	D3		n.g.	12.0*	n.g.	10.8*	n.g.	29.2*	n.g.	48.0*	0.44(1)
	D4		n.g.	11.7*	n.g.	20.9*	n.g.	20.2*	n.g.	46.4*	0.83(1)
	D5		n.g.	10.4*	n.g.	47.4*	n.g.	-	n.g.	42.2*	0.55(1)
[30](2)	E1	Hemp straw	152.9	11.6	688.1	52.0	-	-	481.7	36.4	0.90
	E2		130.8	9.7	719.2	53.1	-	-	503.5	37.2	1.02
	E3		152.9	11.6	584.9	44.2	103.2	7.8	481.7	36.4	1.42
	E4		130.8	9.7	611.3	45.1	107.9	8.0	503.5	37.2	1.91
	E5		130.8	9.7	503.5	37.2	215.8	15.9	503.5	37.2	1.51
	E6		152.9	11.5	481.7	36.1	206.4	15.5	481.7	36.2	1.47
	E7		129.3	9.6	498.0	37	213.4	15.8	498.0	36.9	1.30
	E8		129.3	11.1	498.0	42.5	213.4	18.2	320.1	27.4	2.10
[10]	F1	Mxg (2002)	55.6 – 81.5	9.2 – 12.9*	250.0	39.6 – 41.3*	50.0	7.9 – 8.3*	250.0	39.6 – 41.3*	0.44 – 0.61
	F2	Mxg (2003)	81.0 – 86.5	12.8 – 13.6*	250.0	39.3 – 39.6*	50.0	7.9*	250.0	39.3 – 39.6*	0.33 – 0.44
	F3	M. sacchariflorus (2002)	109.5 – 123.1	16.6 – 18.3*	250.0	37.1 – 37.9*	50.0	7.4 – 7.6*	250.0	37.1 – 37.9*	0.26 – 0.30
	F4	M. sacchariflorus (2003)	123.9 – 142.5	18.4 – 20.6*	250.0	36.1 – 37.1*	50.0	7.2 – 7.4*	250.0	36.1 – 37.1*	0.39 – 0.44
	F5	M. sinensis (2002)	74.4 – 77.6	11.9 – 12.4*	250.0	39.8 – 40.0*	50.0	8.0*	250.0	39.8 – 40.0*	0.23 – 0.31
	F6	M. sinensis (2003)	62.9 – 85.2	10.3 – 13.4*	250.0	39.4 – 40.8*	50.0	7.9 – 8.2*	250.0	39.4 – 40.8*	0.24 – 0.35
	F7	M. robustus (2002)	76.0 – 88.5	12.1 – 13.9*	250.0	39.2 – 39.9*	50.0	7.8 – 8.0*	250.0	39.2 – 39.9*	0.22 – 0.35
	F8	M. robustus (2003)	62.3 – 85.6	10.2 – 13.5*	250.0	39.3 – 40.8*	50.0	7.9 – 8.2*	250.0	39.3 – 40.8*	0.23 – 0.28
[31](3)	G1	Mxg (pre-soaked fibres)	17.4 – 25.0	1.0 – 1.5*	918.6	54.4 – 54.6*	229.7	13.6 – 13.7*	515.3	30.5 – 30.7*	13.4 – 17.6
	G2		34.8 – 50.0	2.3 – 3.3*	816.6	53.4 – 54.0*	204.2	13.4 – 13.5*	458.0	30.0 – 30.3*	6.8 – 11.0
	G3		52.2 – 75.0	3.9 – 5.5*	714.5	52.2 – 53.1*	178.6	13.0 – 13.3*	400.8	29.3 – 29.8*	2.3 – 5.2
	G4	Mxg (cement impregnated fibres)	17.4 – 25.0	1.0 – 1.5*	918.6	54.4 – 54.6*	229.7	13.6 – 13.7*	515.3	30.5 – 30.7*	23.1 – 28.2
	G5		34.8 – 50.0	2.3 – 3.3*	816.6	53.4 – 54.0*	204.2	13.4 – 13.5*	458.0	30.0 – 30.3*	16.0 – 24.1

	G6		52.2 – 75.0	3.9 – 5.5*	714.5	52.2 – 53.1*	178.6	13.0 – 13.3*	400.8	29.3 – 29.8*	10.8 – 16.9

n.g.: not given;
*: calculated values obtained by dividing the weight of the component by the total weight of the mixture;
(1): compressive strength for a curing time of 126 days;
(2): cement replaced by quarry fines;
(3): lime replaced by ground granulated blast furnace slag.

Table 1: Different Mixture compositions per kg/m^3, per wt. % and achieved compressive strength for a curing time of 28 days.

Moreover, S. Elfordy et al. [27] used a different method to manufacture hemp concrete. It consisted of projecting the mixture to a wall or mould through a pipe. The difference here is that the water is only added to the dry-mix (lime and hemp straw) just before it is projected (using a Y-branch pipe). This process gives less time to the fibres to absorb water, and hence less water is needed. By using this method, S. Elfordy et al. [27] reached a compressive strength of 0.85 MPa (**Table 1** (B1)). Furthermore, the high mass of lightweight aggregate (16 wt.% of hemp shives) led to low densities and thus, low thermal conductivities were measured (0.18 - 0.55 W/mK). Very low thermal conductivities (0.046 to 0.069 W/mK) were also reached by E. P. Aigbomian et al. [28] developing a lightweight concrete using woodchip aggregates which resulted in a compressive strength of 0.80 MPa (**Table 1** (C1)).

P. B. De Bruijn et al. [29] created a hemp concrete using aggregates based on dust (4 wt. %), shives (62 wt. %) and fibres (35 wt. %). Besides, the amount of lime presented in **Table 1** (D1 – D5) is a combination of hydrated (25 – 40 %) and hydraulic lime (60 – 75 %). It is good to mention that the mixture using cement and lime reached the highest compressive strength (0.83 MPa). A different hemp concrete was established by V. Dubois et al. [30] using quarry fines instead of cement. They analysed the impact of the relation binder/aggregate (B/A = 4.5, B/A = 5.5) on the compressive strength, the variation of the lime proportions in the binder (0, 15 and 30 %) and the W/C ratio (0.45, 0.7) (**Table 1** (E1 – E8)). They conducted compressive strength tests on cylinders (h=220 mm and d=110 mm) and achieved a maximum stress of 2.10 MPa (B/A = 5.5, Lime proportion = 30 %, W/C = 0.45).

Further investigations on concrete mixtures based on Miscanthus were performed by R. Pude et al., Y. Chen et al. and L. Chupin et al. [10, 31, 32]. R. Pude et al. [10] analysed four genotypes of Miscanthus stems (harvested in 2002 and 2003) for their suitability as lightweight concrete aggregates (**Table 1** F1 – F8). During the mixing procedure, they measured a pH-value of 11-12 on the mixture and the outer ring of the stem. These values imply that the cement paste had moved up to the outer ring. R. Pude et al. [10] concluded that when embedding Miscanthus with cement, the calcium settles mostly on the sclerenchyma of the Miscanthus fibre. The highest compressive strength (0.61 MPa) was achieved using Mxg from 2002. According to R. Pude et al. [10], the reason for this result is the high cellulose content of the fibres (37.9 – 42.0% of dry matter).

L. Chupin et al. [32] compared the use of rhizomes and stems of Mxg as aggregates for LWC. For the mixture prepared with the stem fibres reached almost the double of the tensile strength of the mix with rhizomes. Besides, the Young's Modulus of the mix with the stem fibres was 3.5 – 4 times higher (900 – 1000 MPa) than the mix based on the rhizomes fibres (257 MPa) [32]. Also, L. Chupin et al. measured a higher cellulose proportion for the stem (47.5 % CWR) than for the rhizome (26.9 – 30.7 % CWR). This measurement supports the statement of R. Pude et al. [10] that a high cellulose content has a positive impact on the bond between plant and cement paste.

Furthermore, Y. Chen et al. [31] developed multiple mixtures (**Table 1** (G1 – G6)) using three different lengths of Miscanthus fibres (Powder, 0-2 mm and 2-4 mm). Long strands (2-4 mm) reduced the workability and increased the porosity of the matrix. According to Y. Chen et al. this occurrence also has a positive impact on the acoustic properties since more energy could be absorbed. Furthermore, due to the high water absorption of the fibres [10, 33], Y. Chen et al. analysed the impact of two kinds of pre-treatments on the compression strength, one based on a water saturation of the fibres and the second on impregnation with a cement suspension. The latter presented at least a 45% higher compressive strength after 28 days than the mixtures containing pre-soaked Miscanthus fibres.

The research in this paper aims to develop a concrete mixture using the highest possible amount of Mxg aggregates to create a Miscanthus lightweight concrete that can be used for load-bearing applications on masonry blocks. Except for the mixtures given by Y. Chen et al. [31], no mix could be found in literature that could be used as a load-bearing material. Therefore, the authors examine the physio-chemical processes regarding variations of the mixture components, pre-treatment and long-term deformations. Furthermore, a relation between the compressive strength and the densities has been analysed. Due to the high water absorption capability of the fibres, an investigation on the need of a pre-treatment is carried out. Simultaneously, long-term deformation measurements in shrinkage drains have been performed and analysed by taking into account the type of pre-treatment.

2 MATERIALS AND EXPERIMENTS

2.1 RAW MATERIALS

The current study is performed on Mxg fibres, which were produced by Luxemburgish farmers. Its separation was performed during the harvest process by cutting the stem in threads of a length of 4 to 6 cm. Furthermore, these strands were used within concrete mixtures to create a bearing material, which can be compared to lightweight concrete.

The Miscanthus concrete mixtures consisted of six components (**Table 2)**. The binders were hydraulic lime (NHL 3.5) and cement (CEM I, 42.5R). Instead of increasing the amount of cement, calcium chloride ($CaCl_2$) was used as a mineraliser to increase the compressive strength at an early stage [34-37]. $CaCl_2$ dissolves easily in water, changes the rate of hydration of the mixture, reduces the setting time by 50% and accelerates the hardening procedure of the binder [35, 36]. This stimulation avoided excessive water absorption by the fibres. The amount of $CaCl_2$ was fixed at $12.7\ kg/m^3$. Since the amount of chlorine, according to EN 206:2013 [38], has to be limited for a masonry block, an analysis of the total amount of chlorine in the mixtures is performed. Besides, a superplasticiser (MasterGlenium® ACE 456) is used due to its advantages of accelerating the cement hydration, reducing the water absorption of the cement composite [21] and improving the rheology of the mixture. In the presented mixes, the amount of superplasticiser stayed constant at $5.6\ kg/m^3$. This last represents 1 % of the mass of cement for all the mixtures, except for the section of the cement variation. Besides, due to the high absorption capacity of Miscanthus [31], the fibres were pre-treated before their application in the mixture with a silicate sealant, which is environmentally friendly and diminishes the penetration of water in the threads.

Component	**Density (kg/m^3)**
Miscanthus x giganteus	120
Pure and natural hydraulic lime (NHL 3.5)	740
Cement (CEM I, 42.5R)	3100
$CaCl_2$ (Particle size 2-5mm)	710

Superplasticizer ACE 456	1060
Silicate sealant (liquid)	1100

Table 2: Components and their density

2.2 CHARACTERISATION OF THE MIXTURES

The studied mix design (**Table 3**) is composed of the materials given in **Table 2**. In total five series of compositional mix designs were examined, namely the variation of the amount of Miscanthus, the amount of cement, the W/C ratio, the applied pre-treatment and the density. The effect on the mechanical performance of the hardened specimens in comparison to the reference mixture was evaluated. The reference mixture Ref is composed of 150 kg/m^3 of Mxg, 592 kg/m^3 of cement and 324 kg/m^3 of lime and prepared with a W/C ratio of 0.7 resulting in a pre-determined density of 1 500 kg/m^3. The length of the used Mxg fibres ranged from 40 - 60 mm with a cross-section of 2 - 6 mm. Similar to the observations reported by Mansur and Aziz [39] on jute fibres, the dimensions of the Mxg fibres influenced (decreased) considerably the workability of the mixture. Furthermore, the reference mixture Ref can be compared to a conventional lightweight concrete.

For the first series, the amount of Mxg was varied from 71 to 579 kg/m3 (A1-A4) with a constant W/C ratio of 0.7. The second series comprises the variation of cement content from 150 to 1645 kg/m^3 (B1-B3) with a constant amount of Miscanthus and W/C ratio of 0.7. The creation of the mixtures was planned in wt. % of cement: for mixture B1 20 wt. %, for mixture B2 30 wt. %, for mixture Ref 40 wt. % and for mixture B3 50 wt. %. Although, this leads especially for mixture B3 to a unusual high cement volume, these variations were kept for study purposes but have to be cautiously considered. Subsequently, the W/C ratio was varied from 0.5 to 0.9 (C1-C4) by varying the amount of water, whereas all the other components remained constant in weight. These variations were studied to analyse the impact of the different constituents on the density and on the resulting mechanical performance of the hardened specimens after 28 days of curing. Furthermore, based on the experimental data, the Young's modulus is calculated according to EN1992-1-1:2004 – 11.3.2 [40] using the ultimate load and the density of the specimens. These calculations are experimentally verified using three cylinders (d=15cm and h=30cm) and are based on the mixture which achieved the highest compressive strength.

Moreover, the impact of the pre-treatment on the compressive strength was examined. Two pre-treatments of the fibres were analysed and compared to a non-pre-treated (NPT) mixture (D1-D2 **Table 3**). The pre-treatment was applied to limit water penetration into the fibres. One pre-treatment consisted on covering the Miscanthus fibres with a silicate sealant (S), and the other one was based on a cement, quartz and calcium hydroxide solution (CQCH). The pre-treatment procedure was completed when the fibres were saturated. The final series of mixtures studied the impact of the density variation by varying the compacting intensity (E1-E2). This was performed during the casting procedure, where the taskperson used the hand compaction method by rodding a higher or lower material volume into the mould. The precise filling procedure will be explained on the following section. Finally, all the variations are compared to the reference mixture.

This research aims to use the mixture, which presents the highest compressive strength as well as the lowest shrinkage deformation, within a load-bearing masonry block. However, due to the use of cement and the mineraliser $CaCl_2$, the amount of chlorine in each mixture has to be verified. The European standard EN 206:2013-5.2.8 [38] imposes a regulation for the allowable chloride content in function of the application field of the concrete. Within the framework of the current, the developed mixture is meant to be used within a load-bearing masonry block, so that direct contact with steel reinforcement can be excluded. Thus, the total amount of chlorine should not exceed 1,0 % of the binder mass.

Sample ID	Miscanthus [kg/m^3]	Cement [kg/m^3]	W/C ratio	L/C ratio	Pre-treatment[1]
Reference mixture					
REF	150	592	0.7	0.55	S
Miscanthus variation					
A1	**71**	592	0.7	0.55	S
A2	**238**				
A3	**338**				
A4	**579**				
Cement variation					
B1	150	**150**	0.7	2.17	S

B2		**302**		1.07	
B3		**1645**		0.20	
W/C ratio variation					
C1	150	592	**0.5**	0.55	S
C2			**0.6**		
C3			**0.8**		
C4			**0.9**		
Pre-treatment variation					
D1	150	592	0.7	0.55	**CQCH**
D2					**NPT**
Mass variation					
E1	150	592	0.7	0.55	S
E2					

[1] Distinction between the three pre-treatments:

- S Silica sealant
- CQCH Cement Quartz Calcium Hydroxide
- NPT No Pre-Treatment

Table 3: Variation of the analysed mixtures

2.3 MIXTURE PREPARATION AND FILLING PROCEDURE

The mixtures were realised using a rotating pan mixer (Zyklos, ZK 150 HE). First, the water volume is subdivided into two equal parts (W1 and W2), and the first half of the water volume W1 is mixed to the superplasticiser and the mineraliser. Meanwhile, a dry mixture is set up using the Mxg and the lime. In the next step, the water volume W1 is poured, followed by the cement, and finally the remaining water volume W2 is added to the ongoing mixture. The mixing procedure takes about 7.5 min. The development was performed under laboratory conditions and ambient temperatures of 22 ± 4°C.

After that, the moulds were filled according to the standard EN 196-1:2005-05 by filling them only to half before vibration. Next, the remaining part of the form is filled and anew vibrated. Each test series was composed out of three prisms. The series from the reference mix, from the Miscanthus variations and from the cement variations were also used to conceive three cubes per mixture. Monitoring of the weight was performed during the moulding procedure to guarantee a production of specimens with similar densities leading to similar compressive strength. The moulds, three prisms of 4 x 4 x 16 cm each and three cubes of 15 x 15 x 15 cm each, were placed on a scale during pouring so that it was possible to fill them and simultaneously control the total filling weight. After that, also shrinkage drains (6 x 10 x 100 cm) (**Fig. 2** & **Fig. 13**) were cast and wrapped with cellophane.

All the forms are demoulded after 1 day and wrapped with cellophane foil to avoid desiccation and moisture loss. The prismatic and cubic forms were cured for 28 days, whereas the cellophane is removed after 13 days. Before the compression test, the forms are weighted to measure the density according to EN 12390-7. The compressive strength is measured on three specimens, and a mean value is calculated.

The shrinkage of the mixture is measured using shrinkage drains, which are equipped by a linear variable displacement transformer (LVDT) also known as a displacement transducer with a maximum deviation of 0.2 % for 10 mm (**Fig. 2**). Simultaneously, the environmental conditions of the shrinkage drains are registered by continuous measurement of the temperature and the relative humidity. In this paper, the influence of the pre-treatment of the Mxg fibres on shrinkage behaviour is analysed and compared to a theoretical shrinkage ratio of a lightweight concrete according to the standard EN 1992-1-1:2004 – 3.1.4 [41]. The theoretical shrinkage ratio is calculated using the material properties of a lightweight concrete presented in the EN 1992-1-1:2004 – 11 [40] and the temperature data recorded from the performed measurement.

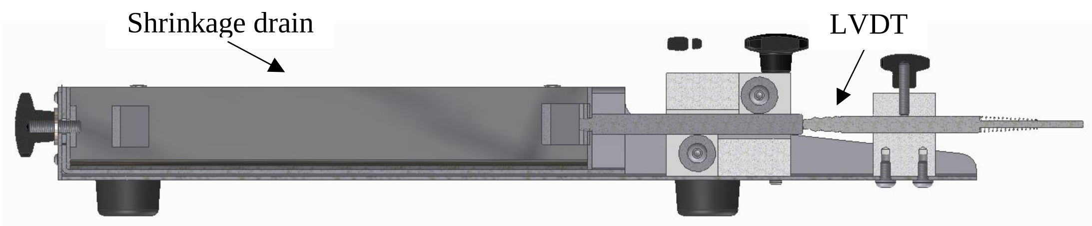

Fig. 2: Shrinkage drain [42]

3 Results and Discussion

3.1 Quantity of chlorine in the mixture

The used mineraliser $CaCl_2$ consists of 64.61 % of pure chlorine. Since the EN 206:2013-5.2.8 [38], which imposes a limit of the chlorine of 1.0 % for the current application, does not specify if the maximum allowed chlorine in a mixture includes the chlorine of the cement, the worst case is assumed, and it has been added to the chlorine of the molecule $CaCl_2$. The cement that has been used in this study comprehends two types of dust, which contain chlorine. In average, each kg of this cement consists of 0.05% chlorine. The total weight of chlorine in the mixture can be defined by summing up the chlorine from the $CaCl_2$ and the cement and relate it to the weight of the binder (cement + lime) that is used in the mixture.

In Fig. 3the chlorine content (in %) of each mixture is represented. The achieved amount of chlorine is defined on the vertical axis, and the mixtures are represented on the horizontal axis. The upper part of each bar represents the chlorine in the cement, whereas the lower part characterises the chlorine in the CaCl2. This last also has the most substantial influence on the total chlorine content of the mixture. Finally, a straight line representing the imposed limit by the EN 206:2013-5.2.8 is presented.

The highest impact on the chlorine content of a mixture is due to the $CaCl_2$. However, except for the variations B1 and B2 all the created mixtures respect the EN 206:2013-5.2.8. Therefore, it can be concluded that the mixtures respect the limits imposed by the EN 206:2013-5.2.8 and can be used for the production of masonry blocks.

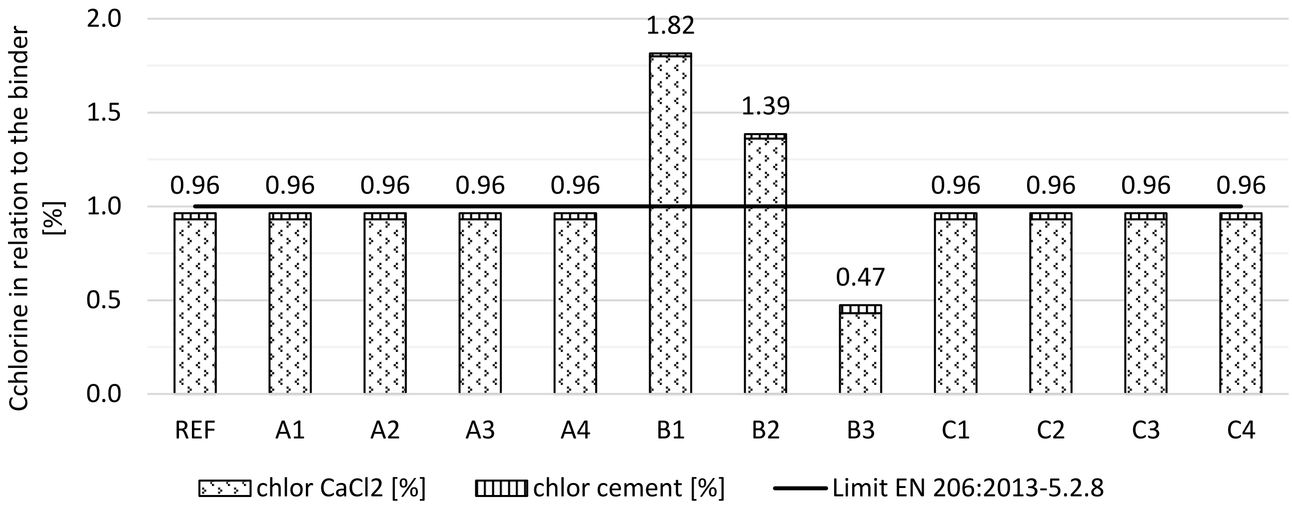

Fig. 3: Chlorine content as a percentage of the binder content of each mixture

3.2 DENSITY AND COMPRESSIVE STRENGTH

The measured density and compressive strength are summarised in **Table 4** for the prismatic shapes and in **Table 5** for the cubic shapes. Since the results are mean values out of three specimens, the standard deviation is determined. In order to compare the density and the compressive strength of the mixtures, a relative difference to the reference mixture is calculated. The mixtures A4 and B1 could not be analysed as they crumbled already while stripping the specimens out of the mould. This effect can be explained by the 1:1 ratio between the amount of Mxg and cement used, which leads to a shortage of cement in the mixture.

Variation	Mix	Prisms					
		Density [kg/m³]	Standard deviation	Relative difference [%]	Compressive strength [MPa]	Standard deviation	Relative difference [%]
Reference	Ref	1221.2	40.8	-	11.7	2.62	-
Miscanthus	A1	1249.4	32.1	+2.3	13.0	2.06	+10.9
	A2*	749.8	2.5	-38.6	2.4	0.11	-79.8
	A3*	593.2	6.1	-51.4	0.8	0.03	-92.9
Cement	B2*	639.9	7.2	-47.6	0.7	0.11	-94.3
	B3*	1017.0	0.5	-16.7	5.3	0.11	-54.6
W/C-ratio	C1	835.7	11.1	-31.6	1.9	0.13	-84.1
	C2	1124.6	50.0	-7.9	9.5	2.32	-19.1
	C3	1339.4	6.9	+9.7	19.3	0.45	+64.1
	C4	1233.3	2.2	+1.0	14.9	0.50	+27.4
Pre-treatment	D1	1309.6	47.1	+7.2	18.8	2.97	+60.5
	D2	1214.5	40.3	-0.5	14.5	4.15	+23.4

Mass	E1*	1060.7	26.9	-13.1	8.0	0.68	-31.9
	E2	1313.3	47.7	+7.5	18.8	1.10	+60.6
* Results are mean values based on two measurements							

Table 4: Results of the density, compressive strength, standard deviation and the relative difference based on the reference mixture for the prisms

Variation	Mix	Cubes					
		Density [kg/m³]	Standard deviation	Relative difference [%]	Compressive strength [MPa]	Standard deviation	Relative difference [%]
Reference	Ref - Cu	1399.1	12.9	-	13.8	1.18	-
Miscanthus	A1 - Cu	1523.6	63.5	+8.9	25.3	8.56	+83.6
	A2 - Cu	831.0	11.9	-40.6	2.1	0.08	-85.1
	A3 - Cu	621.8	17.7	-55.6	0.4	0.07	-97.4
Cement	B2 - Cu	688.4	4.5	-50.8	0.3	0.02	-97.9
	B3 - Cu	1309.0	31.4	-6.4	12.4	0.69	-9.8

Table 5: Results of the density, compressive strength, standard deviation and the relative difference based on the reference mixture for the cubes

3.2.1 MISCANTHUS VARIATION

Considering the Miscanthus variation, it is obvious that a reduction of the amount of Mxg to 71 kg/m^3 has a beneficial impact on the compressive strength. Furthermore, it can be noticed that on the one hand, halving the amount of Mxg from 150 to 71 kg/m^3 increases the density by 2.3% (**Table 4**). The compressive strength is increased by 10.9% for the prismatic specimens (**Table 4**) and by 83.6% for the cubic specimens (**Table 5**). This difference can be explained by the increased shape of the cubes and the low ratio between the Miscanthus and the cement (0.12:1). On the other hand, increasing the Mxg from 150 to 338 kg/m^3 (mix A3) reduces the density by 51.4% (prisms), resp. 55.6% (cubes). Furthermore, the achieved compressive strength is below 1 MPa, independent from the shape of the specimen.

In general, an increase in the amount of Miscanthus leads to a clear decrease in the density (**Fig. 4**) and the compressive strength (**Fig. 5**). It also has to be mentioned that independent from the mix; the cubes had a higher density, as well as a higher standard deviation, than the prisms. This occurrence could be due to higher compaction during the filling procedure, which is to some extent depending on the person in charge. The difference in the density decreases with an increasing amount of Miscanthus. The trend of the compressive strength behaves differently. For the mix using a low amount of Miscanthus (A1), the cubic specimens present almost the double compressive strength than the prismatic ones. Nevertheless, increasing the amount of Miscanthus reduces the difference, and from one point upwards (150kg/m^3 of Miscanthus), the compressive strength of the cubic samples is even lower than the one of the prismatic ones (**Fig. 5**). However, the difference between both shapes remain small (0.3 – 0.4 MPa).

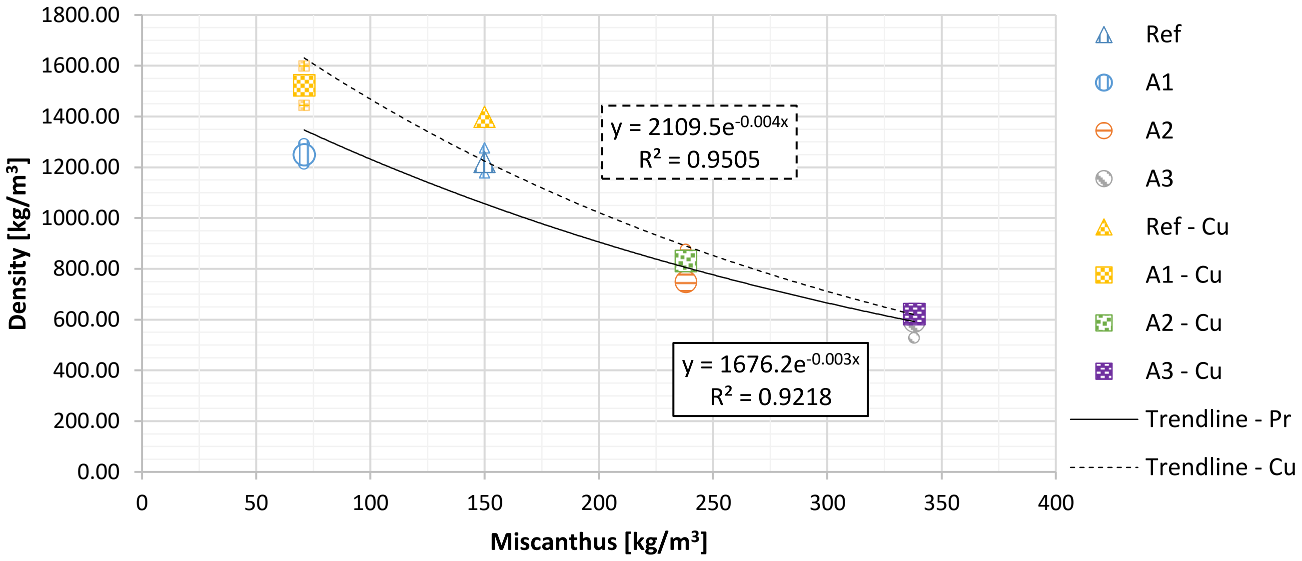

Fig. 4: Density of prisms and cubes in function of the amount of Miscanthus in the mixture (The big markers correspond to the mean value of the small markers)

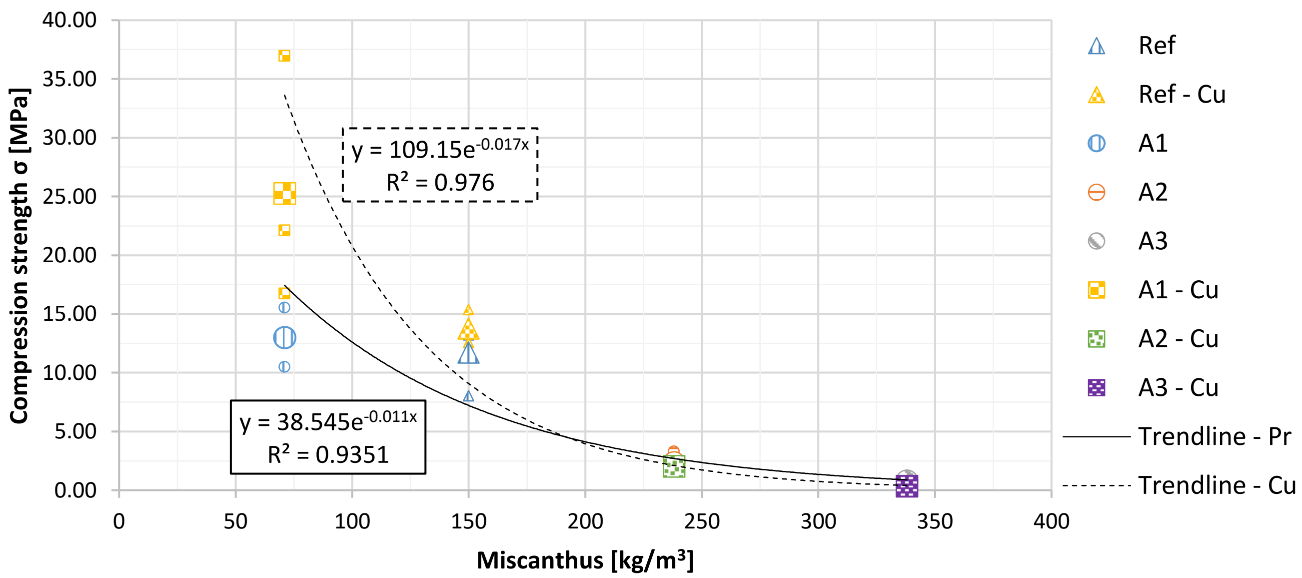

Fig. 5: Compressive strength of prisms and cubes in function of the amount of Miscanthus in the mixture (The big markers correspond to the mean value of the small markers)

3.2.2 Cement variation

The densities of the cement mixes (B2-B3) (**Table 4** for prisms and **Table 5** for cubes) are lower than the density of the reference mixture. It can be observed that the relative difference of the density of mix B3 (higher amount of cement compared to the reference mixture) is different for prisms (-16.7%) and cubes (-6.4%). However, a similarity in the density can be noticed for the mixture B2 (-47.6% for prisms and -50.8% for cubes). The impact of the reduction of the cement amount can also be observed by visual comparison (Ref mix (a-b) **Fig. 6**; B2 mix (c-d) **Fig. 6**).

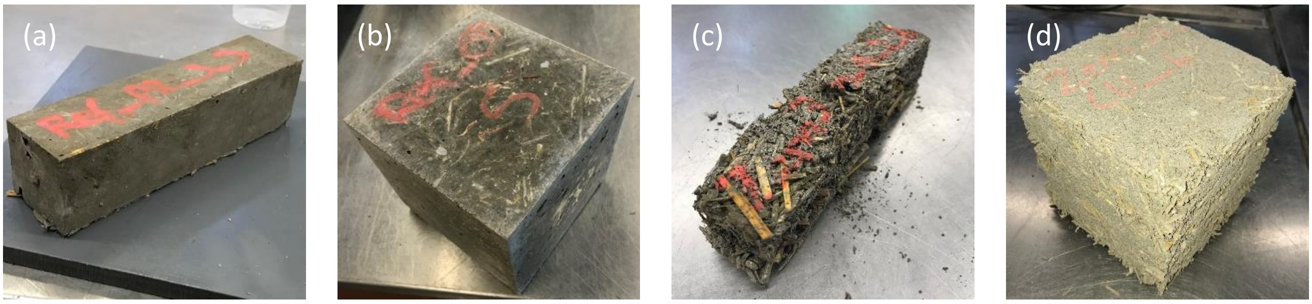

Fig. 6: (a) - (b) specimens from mixture Ref and (c) - (d) specimens from mixture B2

Moreover, the variation of cement amount results in a decrease in the compression strength compared to the reference mixture (Ref). The fact of increasing the amount of cement and implying with this a reduction of the compressive strength was unexpected. Therefore, a microstructural analysis is performed on the mixture B3 using SEM (**Fig. 7**). Due to the low ratio between Mxg and the cement (0.09:1), this mixture is very close to a standard mixture for normal concrete where W/C ratios of 0.3 – 0.4 are usual. Using here such a high W/C ratio of 0.7 implies a very liquid cement paste and provokes the formation of air voids, which were visualised using SEM. These cavities disrupt the bond between the Mxg and the cement, which leads then to a reduction of the compressive strength (prisms -54.6% and cubes -9.8%). Similar to mix A1, the difference of the compressive strength between prisms and cubes is due to the low ratio between Miscanthus and cement (0.09:1).

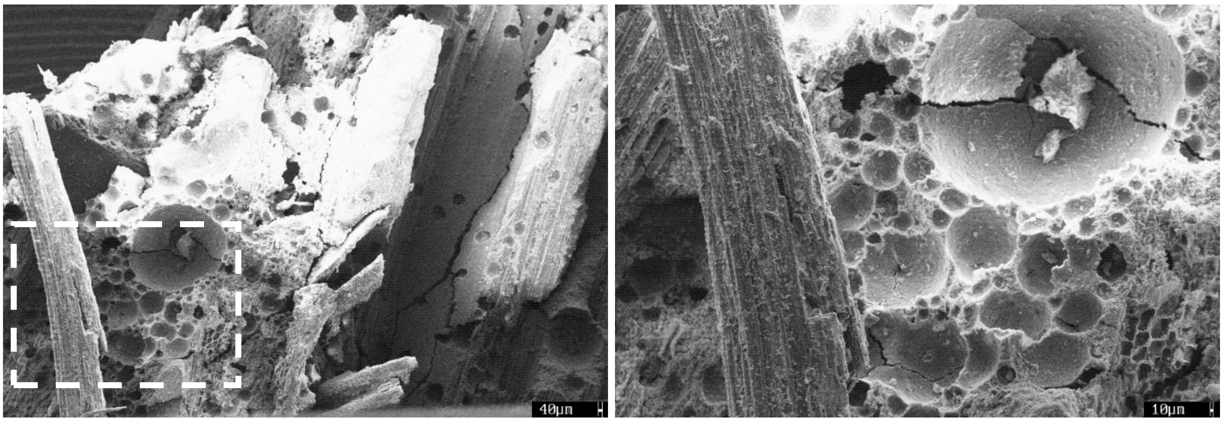

Fig. 7: SEM of the mixture B3 at a range of 40 μm and the marked region at a range of 10 μm

The compressive strength reached by the cubes on the mix B3 is also due to the higher availability of hydration products. Therefore, it can be assumed that the water inside the cube is released slower than this is the case for the prismatic shape. Hence, a slower release of water corresponds to a slower loss of weight, a slower diminution of the density and a longer hydration process of the cement in the mixture. Contrarily, the lower compressive strength of the cubes compared to the prisms (mix B2) is due to the higher Mxg cement ratio (0.50:1). The strands of the Mxg are composed of many air voids, as observed by P. Klímek et al. [7], and thus reduce the density and the achieved compressive strength. Thus, a faster decrease of the weight happens during the curing process, which implies a faster decrease in the density. Therefore, it can be concluded that the difference between the compression strength is related to the airtightness of the specimen and the ratio between the Mxg and the cement.

3.2.3 W/C RATIO VARIATION

Moreover, decreasing the W/C ratio leads in principle to a reduction of the density and of the compressive strength. The relative difference of the mixture C2 to the mix Ref is -7.9% for the density and -19.1% for the compressive strength. Since the Miscanthus fibres present a high water absorption [10, 33], reducing the W/C ratio results in less water available for the cement reaction. During hydration, the water, which is first absorbed by the fibres is released afterwards during the fifth hydration phase of cement (steady-state phase) [43], and partly reacts with the non-hydrated cement particles and partly evaporates. Nonetheless, a continued decrease of the W/C ratio (mix C1) shows a relative difference of -31.6% for the density and -84.1% for the compressive strength.

An increase of the W/C ratio represents a gain on the density (+9.7% on C3 mix and +1.0% on C4 mix) and on the compressive strength (+64.1% on C3 mix and +27.4% on C4 mix). Nevertheless, mix C4 shows that the used water amount exceeds the saturation point of the Miscanthus fibres and the water needed for the cement hydration, which implicates bleeding of the mixture.

Furthermore, it is visible on the prismatic specimens, that decreasing the W/C ratio of the mixture Ref results in a decrease of the compressive strength. However, increasing the W/C ratio to 0.8 produces the highest compressive strength presented in this paper for the prismatic samples with 19.3 MPa. The increase of the compressive strength is confirmed by a visible decrease of the porosity with an increase of the W/C ratio (**Fig. 8**). Nonetheless, a further increase of the W/C ratio to 0.9 reduces the compressive strength (14.9 MPa). As for the mixture B3, a microstructural analysis (SEM) is performed on the mix C4 which makes void spaces induced by earlier existent air bubbles visible (**Fig. 9**). Furthermore, a crack in the binder is becoming apparent, which is a consequence of the shrinkage process in the microstructure of the mix. This perturbation of the bond between the cement matrix and the Mxg fibres results in a reduction of the compressive strength by 4.4 MPa compared to the C3.

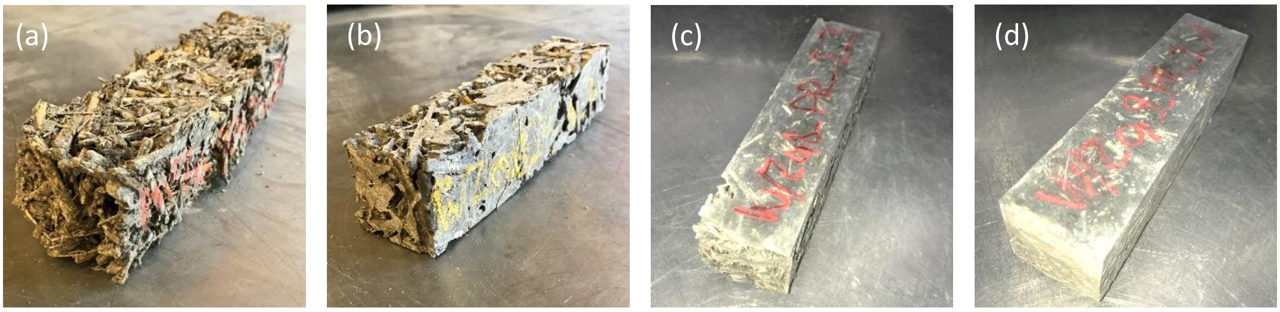

Fig. 8: Prisms of the mixtures (a) C1; (b) C2; (c) C3; (d) C4

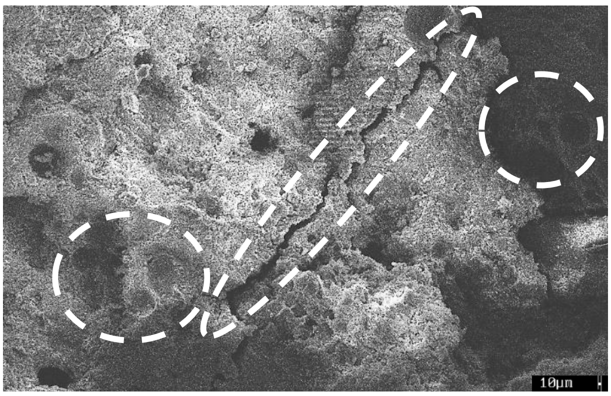

Fig. 9: SEM of the mixture C4 pointing out the void spaces and a crack

Nevertheless, a W/C ratio below 0.7 (mix C1 and C2) does not provide sufficient water for the cement reaction as one part of the water is absorbed by the Mxg and is therefore not available for the cement hydration. This lack of water induces the specimen to have high porosity ((a-b) **Fig. 8**). The remaining water, which is then used by the cement to react, is not enough for total hydration and leads to a reduction of the compressive strength.

3.2.4 RELATION BETWEEN THE DENSITY AND THE COMPRESSIVE STRENGTH

Furthermore, the relation between the compressive strength and the density is analysed for all mixes of the prismatic and cubic specimens (**Fig. 10**), and a parabolic regression can be observed with an increasing density. A similar observation was done by Sagmeister [44] for a lightweight concrete without fines. It is noticeable that with an increasing density of the Mxg concrete, the compressive strength of the prisms is converging to the results of Sagmeister. The differences vary from 5 to 50 % by increasing the density. It is perceptible that a higher density implies a higher compressive strength. This statement can be verified by comparing the mixture Ref, E1 and E2 since they have the same composition. The difference was made during casting, where a density increase of 100 kg/m^3 for the prisms signified that 25g more material was used per prism. It is observable that the highest results were obtained by mixture E2 and the lowest by mixture E1. These findings induce that the compactness of the mixture during casting has a high impact on the compressive strength after a curing time of 28 days. However, it is very challenging to obtain the same density for the same mixture when producing the mixtures manually, since this is mostly dependent on the personal approach of the person in charge of this task. Nonetheless, it is possible to predict an approximation of the compressive strength of the mixtures after 28 days of curing in function of the weight of the prisms at casting. Furthermore, it can be noticed that the shape of the specimen influences the achieved compressive strength. The shape has an impact on the compressive strength, which reaches a difference of 65.2% considering a low density of 600 kg/m^3, whereas this impact is gradually reduced to 38.1% for a higher density of 1300 kg/m^3.

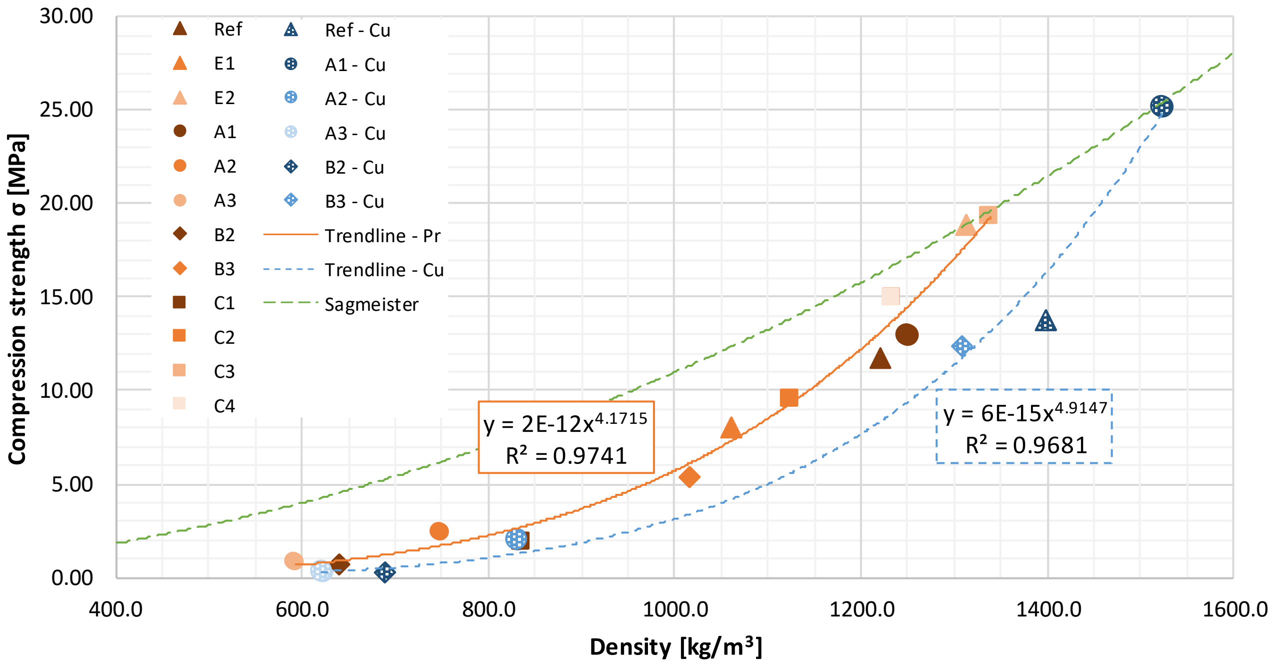

Fig. 10: Compressive strength in function of the density for prisms compared to the results given by Sagmeister [44] for a lightweight concrete without fines

3.2.5 Pre-treatment variation

Moreover, the impact of the pre-treatment of the Miscanthus fibres on the compressive strength is analysed. Therefore, the density and compressive strength (mean values of three tests per mixture) of the mixture Ref are compared to the mixture D1 and D2. Both mixtures achieved a higher compressive strength than the mixture Ref (+60.5 % for D1 and +23.4 % for D2). D1 reached the highest compressive strength and density. However, the mixture D1 has a higher density than the mixture Ref. Due to the close link between compressive strength and density, the mixture D1 has to be compared to mixture E2. As previously mentioned, the mixtures E1 and E2 have the same components as the mixture Ref (**Table 3** and section 3.2.4). The only difference is given by distinct densities. Consequently, a comparison of the compressive strength of D1 to E2 is possible and shows similar results for the density and the compressive strength. Nonetheless, comparing the mixture D2 to Ref the densities are similar, but the mixture that uses Mxg fibres without pre-treatment (D2) reaches a higher compressive strength (14.5 MPa) than the mixture Ref (11.7 MPa).

A microscopic analysis shows a clear difference between the non-treated and the treated Mxg fibres (**Fig. 11**). A non-treated fibre presents an explicitly visible epidermis, outer ring and parenchyma ring (**Fig. 11** (a)). This is not the case for a fibre treated with a silicate sealant. In this case, the outer ring, as well as the parenchyma of the fibre, is mostly filled (**Fig. 11** (b)). This fact avoids a high absorption of water from the Miscanthus fibre, which induces that more water is available for the cement hydration. The Miscanthus fibre treated with the CQCH treatment shows an almost complete layered cross-section (**Fig. 11** (c)). The analysed fibre was not fully covered by the pre-treatment product during the application procedure and a small part of the epidermis, as well as the outer ring, are still visible. The layer over the fibres can be considered as a cement hydration product. The consequence of completely covered Miscanthus fibres is that less water can be absorbed during the mixing procedure. However, the disadvantage of the covered fibres is also that the binder cannot enter the fibres and therefore, the bond between the binder and the Mxg is reduced.

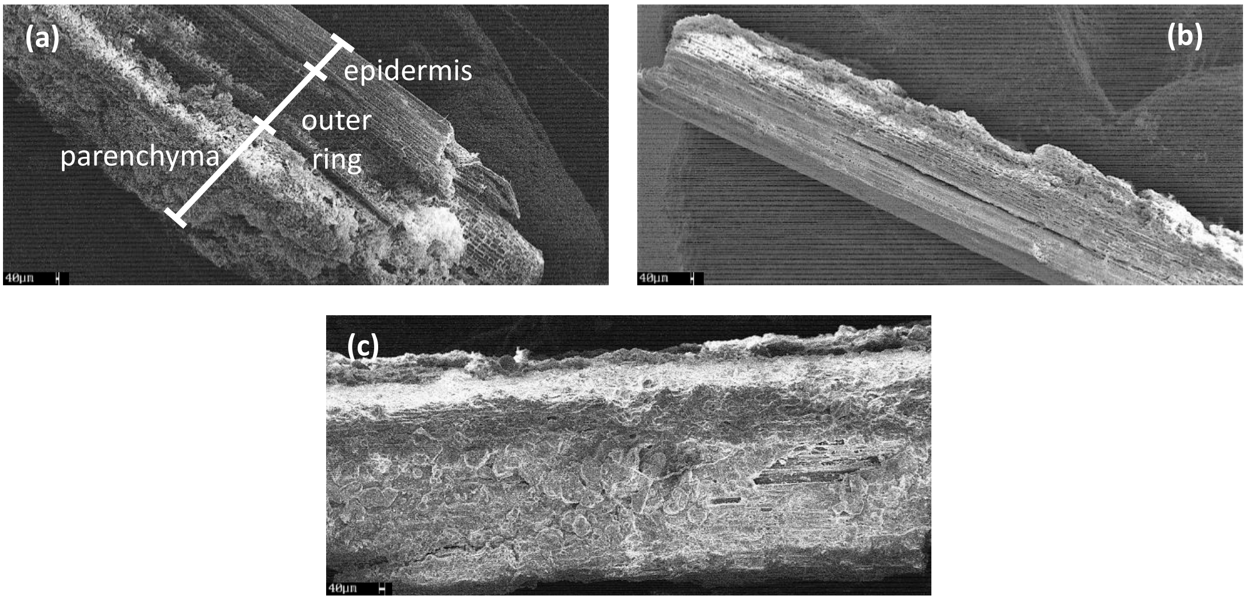

Fig. 11: SEM of Mxg fibres (a) non-treated (b) treatment based on silicate sealant (c) treatment based on CQCH

3.3 Analysis of the Young's Modulus

In **Fig. 12**, the compressive strength of the mixtures presented in **Table 4** (results of the prisms) are illustrated in function of the Young's Modulus. The Young's Modulus is calculated according to EN1992-1-1:2004-11.3.2 [40] using the density and the achieved compressive strength by the prisms at the age of 28 days as follows:

$$E_{lcm}[MPa] = 22 \cdot \left(\frac{compressive\ strength}{10}\right)^{0.3} \cdot \left(\frac{density}{2200}\right)^{2}$$

Thus, a parabolic regression with a determination coefficient of R^2=0.9984 can be observed relating all the prismatic shapes of the mixtures. Besides, the Young's Modulus is calculated for the measurements of Sagmeister and represented in the same figure. As expected, a positive correlation between the compressive strength and the Young's Modulus is visible. On one hand, the mixtures with a Mxg to water ratio between 0.51:1 (mix C1) and 0.82:1 (mix A3) reach a Young's Modulus below 2.0 GPa. On the other hand, a Young's Modulus above 9.0 GPa is reached by the mixtures E2 and C3, which show to have a higher stiffness leading to a smaller deformation of the shape due to loading. At this point, the relation between the Mxg and the water amount is not taken into consideration since they are all below 0.5:1. Furthermore, an increasing Young's Modulus converges to the curves provided by Sagmeister. Therefore, it can be concluded that the Young's Modulus reached by the mixtures based on Miscanthus can be compared to the Young's Modulus of the lightweight concrete studied by Sagmeister.[44]

In addition, three cylinders are produced using the same components as mixture C2. However, compared to the studied mixture C2 on the prisms, the three cylinders presented a considerably lower density. The results of the achieved density, compressive strength and Young's Modulus are reported on **Table 6**. These two last are added to **Fig. 12** (red crosses) and it is visible that they are situated between the trendline based on the presented mixtures and the trendline studied by Sagmeister. [44]

Specimen	Mix	Density [kg/m^3]	Compressive strength [MPa]	Young's Modulus [GPa]
Cylinder 1	C2	830.2	1.59	0.67
Cylinder 2		897.2	1.74	0.73
Cylinder 3		978.7	1.96	0.97

Table 6: Results of the density, compressive strength and Young's Modulus of the three cylinders

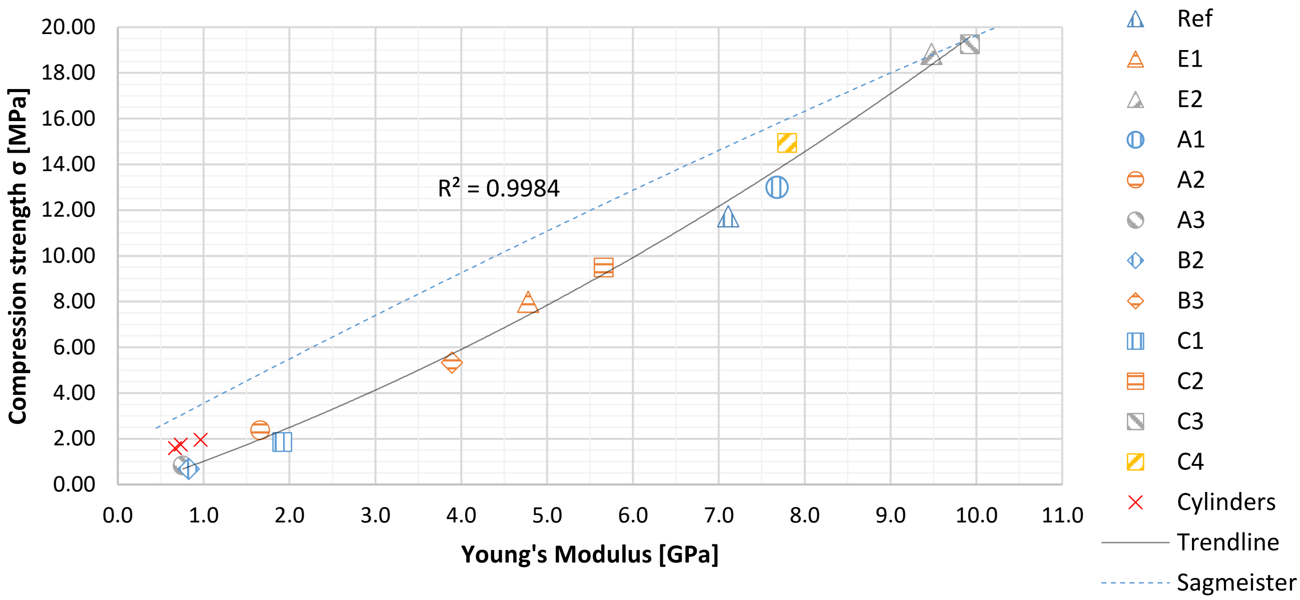

Fig. 12: Young's Modulus of the tested prisms in relation to their compressive strength

3.4 Analysis of the hygric properties of Miscanthus lightweight concrete

The hygric properties of the reference mixture Ref are measured on shrinkage drains (**Fig. 13**) for 609 days (**Fig. 14**), as well as the relative humidity and the room temperature. These are presented on the lower and middle graph of **Fig. 14**. The upper graph presents the shrinkage development in $\mu m/m$ of three drains (Drain-1_S, Drain-2_S and Drain-3_S) based on the mixture Ref (**Table 3**) in function of time. The drains were wrapped with cellophane for 90 days to analyse the swelling behaviour of the specimens. The cellophane prevented direct contact to the outer ambient. After casting, first a swelling of the mixture can be observed. This expansion occurring after casting is the result of the Miscanthus fibers absorbing moisture from the matrix and presenting thus swelling. This process reached a value of 500 $\mu m/m$. The cellophane was discarded, and the shrinkage procedure of the mixtures started. With the reduction of the internal relative humidity over time due to the hardening process, the mixture starts desorbing which results in a global increase of the shrinkage values over time.

Fig. 13: Shrinkage drain with the mixture before applying the transducer

During the measurement period, the registered relative humidity fluctuated, which was related to the ambient temperature and humidity changes in the room the drains have been stored. Therfore, in addition to the main global increase of shrinkage variations due to the fluctuation of the external temperature and humidity could be observed. In general, an increase in temperature lead to a decrease in the shrinkage as could be observed at a curing time of 275 - 285 days: the increase of the temperature from 9°C to 16°C at a relative humidity above 70 % lead to a swelling of the mixture. However, this only happened during the periods where a high relative humidity was present (the period from 400-420 days). This statement was confirmed at the age of 320 days. Here, the increase in temperature with a ΔT= 7°C (from 10°C to 17°C) and a relative humidity of 50 % does not induce any swelling. Furthermore, after a curing time of 480 days the drains showed a horizontal tendency. Therefore, it can be assumed that the degree of shrinkage is achieved and reached an average deformation of 2244 $\mu m/m$.

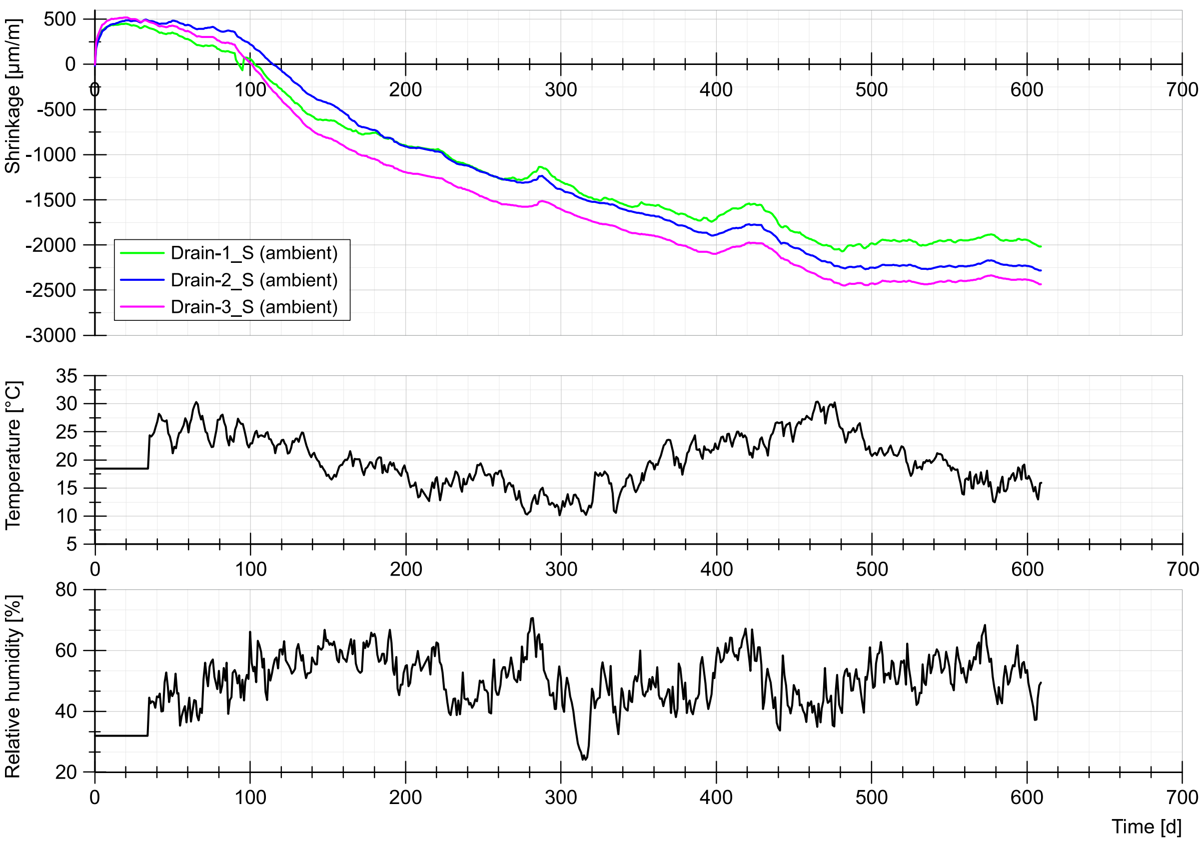

Fig. 14: Shrinkage drains of the mixture Ref

In order to compare the recorded shrinkage deformation, the shrinkage development of several conventional LC according to the standard EN1992-1-1:2011-01 is presented in **Fig. 15**. These results are not pretended to predict or model the shrinkage behaviour of Miscanthus lightweight concrete but aim to add a comparison between the experimental data and a conventional LC according to the standard EN1992-1-1:2011-01. The shrinkage course of the latter is calculated analytically according to EN1992-1-1:2011-01 by using the specific environmental conditions from **Fig. 14**. These analytical calculations of the LC show a swelling lower than 50 $\mu m/m$ for the first days. According to the calculations, LC reach a value between 500 and 1 000 $\mu m/m$ already after 70 days. The deformation is dependent on the type of the LC. However, the highest shrinkage deformation of 1 000 – 1 200 $\mu m/m$ is achieved by the LC12/13, which is less than half of the degree of shrinkage of the mixture Ref. Furthermore, the high value of shrinkage (2244 $\mu m/m$) could induce more warping and cracking, which makes the Mxg concrete mixture based on a silicate pre-treatment (section 2.2 - **Table 3**) not ideal considering long-time deformations.

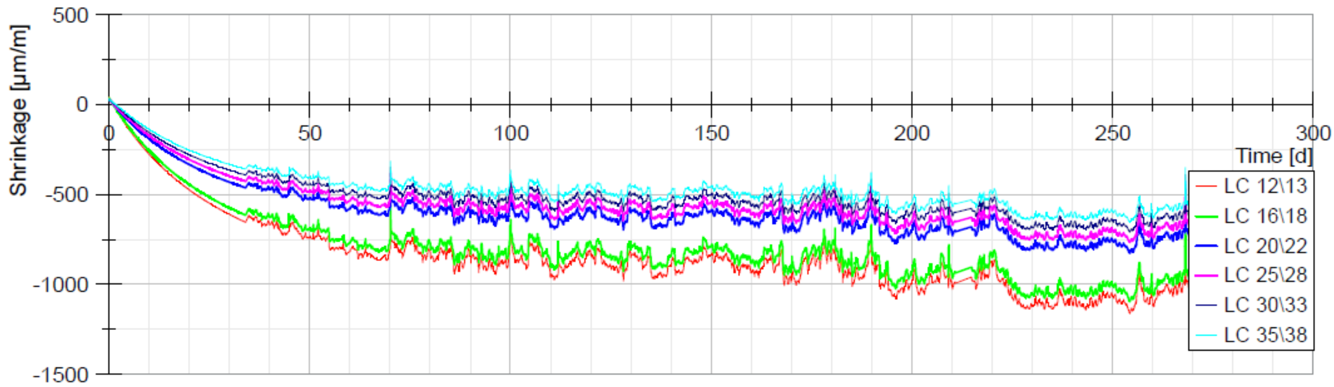

Fig. 15: Shrinkage drain of lightweight concrete calculated analytically using the environmental conditions from **Fig. 14**

Furthermore, the impact of the pre-treatment on the shrinkage deformation is analysed. Therefore, the degree of shrinkage is also measured for the mixture D1 on three drains (Drain-1_CQCH, Drain-2_CQCH and Drain-3_CQCH) (**Fig. 16**). The deformation, as well as the temperature and the relative humidity, were recorded for 574 days. As before, the drains were wrapped with cellophane but only for 56 days. The early start of shrinkage of Drain-1_CQCH was due to a leakage in the cellophane that allowed an exchange with the environment. After a period of 240 days, the drains were moistened, and the velocity of shrinkage increased until reaching the previous path of the shrinkage deformation. The final deformation with an average of 2 473$\mu m/m$ was achieved after a curing time of 440 days.

It can be concluded that comparing the pre-treatment based on a silicate sealant and the pre-treatment based on CQCH; a higher shrinkage deformation is generated by the mixture D1 (2 473$\mu m/m$). However, the differences remain smaller than 10% but are 2.2-2.4 times higher than the deformations achieved by a LC12/13 (**Fig. 17**). Furthermore, the presented mixtures based on Miscanthus aggregates showed to achieve lower shrinkage deformations than a Hemp-concrete ($4500 - 8500\ \mu m/m$) or a Flax-Hemp-concrete ($4000 - 7500\ \mu m/m$) [22].

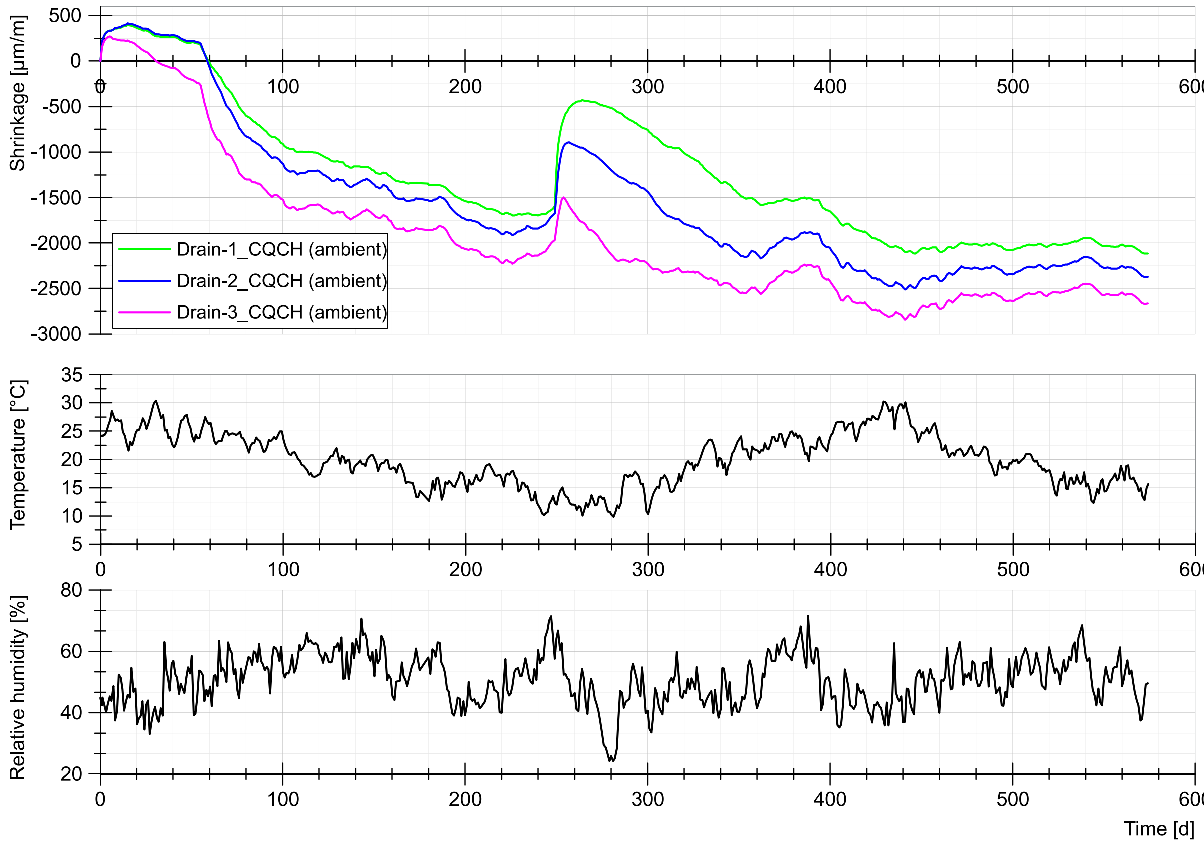

Fig. 16: Shrinkage drains of the mixture D1

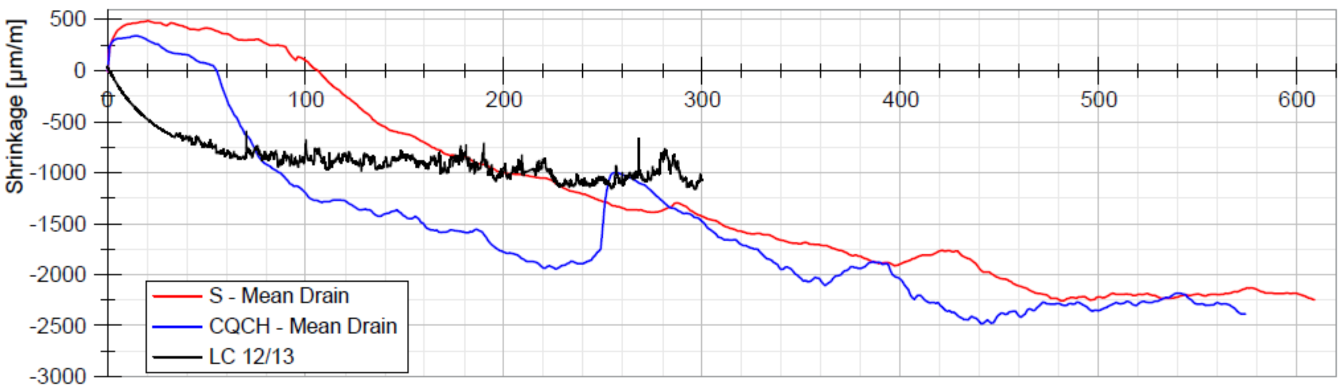

Fig. 17: Comparison of the shrinkage deformations between the mean drains of the mixture Ref, D1 and the calculated LC12/13

4 Conclusions

This study reached to develop an LC based on Mxg fibres that can be used as a bearing material. The identification of a mixture of the Mxg lightweight concrete with a bearing capacity is achieved by varying the components of the mixture. The conclusions taken from this paper are summarised in the following:

- The reference mixture Ref using 150 kg/m^3 of Mxg fibres, which were pre-treated with a silicate sealant, allows achieving a compressive strength of 11.7 MPa (for prisms, and 13.8 MPa for cubes) with a density over 1000 kg/m^3. However, increasing the ratio between Mxg and cement from 0.25:1 (mix Ref) to 0.40:1 (mix A2) reduces the compressive strength by -79.8 % for the prismatic specimens and by -85.1 % for the cubic specimens.
- Any variation of the amount of cement resulted in a decrease in the compressive strength. Since the W/C ratio remained unchanged, an increase of the cement amount induced a proportional increase of the water volume and lead therefore finally to air voids in the hardened matrix, which disrupt the bond between the Mxg and the binder.
- A W/C ratio of 0.8 (mix C3) leads to a compressive strength of 19.3 MPa, which is higher (+64.1 %) than the reference mix. A change of this ratio to 0.9 (mix C4), 0.6 (mix C2) or 0.5 (mix C1) induces a loss in the compressive strength of at least -19.1 % compared to the reference mix.
- An increase in the density of the mixtures leads to a parabolic increase of the compressive strength independent from the shape. For the prismatic specimens, a density below 900 kg/m^3 presents a compressive strength below 4 MPa and a density above 1300 kg/m^3 leads to a compressive strength above 18 MPa.
- A mixture with a CQCH pre-treatment (D1) achieved a similar density and compressive strength as the mixture E2 using a silicate sealant as a pre-treatment. Hence, both pre-treatments have the same impact on the compressive strength.
- A mixture without any pre-treatment of the fibres (D2) conducts to a compressive strength of 14.5 MPa, which is higher than the mixture Ref (11.7 MPa), whose fibres were pre-treated using a silicate sealant.
- A compressive strength of 18.8 MPa leads to a Young's Modulus of 9.5 GPa (mix E2). A mixture with a Young's Modulus of 3.9 GPa (mix B3) presents a compressive strength reduced by 72 % compared to mix

E2. Furthermore, if the relation between the used Mxg and water is above 0.50:1, a Young's modulus below 2 GPa is expected.

- A pre-treatment of the fibres using a silicate sealant presents a 10 % lower shrinkage degree than a mixture using CQCH pre-treated fibres, which signifies that the pre-treatment has an influence on the shrinkage degree. Therefore, it can be concluded that a pre-treatment based on a silicate sealant shows to be more beneficial considering the long-term deformation than a CQCH pre-treatment.

Finally, it can be concluded that according to the results presented in this paper, the theoretical best mixture considering the compressive strength, not taking into account a study of the combination of the materials, would constitute of 150 kg/m^3 of Miscanthus, 592 kg/m^3 of cement and a W/C ratio of 0.8. Furthermore, considering the long-term deformation a pre-treatment based on a silicate sealant would be more beneficial than a CQCH pre-treatment.

This field of sustainable construction materials needs further investigations to enlarge the experimental database and evaluate the crack propagation due to shrinkage or tension as well as the deformation behaviour due to creeping. Also, cost-effective analysis of the lightweight concrete based on Miscanthus fibres needs to be performed.

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