EcoGRAFI

2nd International Conference on Bio-based Building Materials &
1st Conference on ECOlogical valorisation of GRAnular and FIbrous materials

June 21th - 23th 2017
Clermont-Ferrand, France

USING ALTERNATIVE BINDERS FOR THE DEVELOPMENT OF FLAX FIBRE REINFORCED MORTARS

J. Page[1,2]*, F. Khadraoui[1], M. Boutouil[1], M. Gomina[2]

[1] École Supérieure d'Ingénieurs des Travaux de la Construction de Caen, Epron, France
[2] Université de Caen Normandie, CRISMAT, UMR6508, CNRS-ENSICAEN, Caen, France

*Corresponding author; e-mail: jonathan.page@esitc-caen.fr

Abstract

The primary concern for plant-fibre reinforced cementitious composites is the durability of the fibres in the highly alkaline environment of the cement matrix. The flax fibres reinforced cementitious composites (FFRM) may undergo a reduction in strength and toughness as a result of weakening of the fibres by a combination of alkali attack and mineralisation through the migration of hydration products to the flax fibre lumen. This paper presents a way to improve the durability of FFRMs by a replacement of the ordinary Portland cement matrix by alternative binders such as metakaolin, ground granulated blast-furnace slag or sulfo-aluminous cement. The properties of fresh mortars were first studied (workability, entrapped air, fresh density). The mechanical properties (3-points flexural and compressive tests) were then tested after several cure periods: 7, 28 and 90 days. In fresh state, the use of alternative binders does not significantly affect mortar properties. However, the GGBS improves the fresh mortar workability. The additives influence the compressive strength of the mortars. C$\bar{S}$A cement results in a significant decrease, regardless of the curing period. With MK and GGBS, the 7-day strengths are lower due to the pozzolanic reaction. However, those at 90 days are equivalent to CEM-100 and even higher with GGBS. The use of alternative binders limit the degradation of the fibers between 28 and 90 days of treatment. The toughness has been improved using some alternative binders, such as calcium sulfo-aluminous cement.

Keywords:
Flax fibre; Fibre-reinforced mortar; Binder; Flexural strength; Toughness

1 INTRODUCTION

For several decades, fibres are used in cementitious materials to improve the toughness and post-cracking behaviour. The most commonly used in cementitious composites are steel fibres, glass fibres and polypropylene fibres. But all these reinforcement materials have the disadvantage of being derived from non-renewable resources. Economic issues related to the rising costs of fossil resources, their increasing scarcity, and environmental impacts inherent to their production therefore lead to explore other material sources. Based on this observation, plant fibres could be a solution for the future of the construction industry. Among the plant fibres, flax stands out because of its high mechanical properties and its low density.

Much researches dealt with the incorporation of bio-based fibres in cementitious materials. It was highlighted that in fresh state, natural fibres affect the rheology of the material [Chafei 2014, Le Hoang 2012]. These rheological disturbances are mainly attributed to the high demand for water due to the high water absorption capacity of flax fibres (up to 150 % of dry fibre mass) and their high specific surface area [Chafei 2015]. In hardened state, composites reinforced with plant fibres present an improvement of the flexural toughness or strength and an increased ductility [Mechanical performance of hemp fibre modified mortar

Mechanical performance of hemp fibre modified mortar

Mechanical
performance of hemp
fibre modified mortar 2013, Sedan 2008]. The transition from a brittle matrix to a ductile fibered composite having a controlled post-peak behaviour is noted by several authors. However, this change in the behaviour is not always accompanied by an improvement in the flexural strength [Kriker 2005].

Despite the encouraging results obtained on the mechanical properties of vegetable fibre-reinforced composites, numerous studies show durability issues of the fibres in contact with alkaline cement-based matrix. After 12 months of natural aging, Sedan *et al.* observed a flexural behaviour significantly modified [Sedan 2007]. The strength in the first crack is relatively constant compared to tests at 28 days, however composites no longer exhibit toughness after aging, and therefore have a similar brittle fracture than a non-fibre-reinforced matrix. Similar results are obtained by Mohr *et al.* on cementitious composites reinforced with kraft pulp [Mohr 2006]. Most authors have noted, in parallel with the loss of toughness, an increase in first crack strength [Akers 1989, Kriker 2008, Soroushian 1994, Toledo Filho 2000].

The loss of toughness of the plant fibre-reinforced composites can be explained by the degradation of these fibres in contact with the highly alkaline cementitious matrix. The degradation of vegetable fibres in an alkaline environment wold be due to the partial or total dissolution of the cellulose, hemicelluloses and lignin by alkaline hydrolysis [Gram 1983]. Moreover, in contact with calcium hydroxide, authors have observed a more intense degradation of the fibres. The precipitation of hydroxide or calcium carbonates on the surface or in the pores of plant fibres leads to their stiffening and embrittlement [Gram 1983, Bentur 2007].

Gram highlights the ineffectiveness of treatments by impregnation of substances supposed to react with the fibres to form compounds insensitive to alkaline attack (sodium silicate, sodium sulphite, magnesium sulphate, etc.) [Gram 1983]. None of these treatments have improved the fibres durability in a cement matrix. Other hydrophobic organic coating processes (acrylic polymer, paraffin, linseed oil, etc.) have been investigated by other authors [Juarez 2007, Khazma 2011, Sellami 2013]. However, these treatments have also been ineffective in improving the durability of the fibres in a cementitious matrix.

Another option for improving the durability of vegetable fibre-reinforced composites could be to transform the matrix to reduce its aggressiveness towards these fibres. As seen previously, this degradation is related to the highly basic pH of the cement matrix and to the presence of calcium hydroxide which is caused to diffuse towards the fibres and to reprecipitate therein causing their mineralisation [Toledo Filho 2000]. This works investigate a way to improve the durability of flax-fibre reinforced cementitious composites using a partial or total replacement of the ordinary Portland cement (OPC) matrix by alternative binders such as metakaolin, ground granulated blast-furnace slag or sulfo-aluminous cement.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Binders

The cement used in this study is a CEM I 52.5 N white Portland cement in accordance with EN 196-1 standard. The clinker ratio is 98% (2% of limestone). The compressive strength on standardized mortar at 28 days is 71 MPa.

To decrease the durability of FFRMs, three different alternative binders were used. The first one is a calcium sulfo-aluminate cement (C$\bar{S}$A). The main hydration product of C$\bar{S}$A are ettringite and calcium monosulfoaluminate hydrate, but does not produce Portlandite and CSH as OPC. [Winnefeld 2010]. The clinker ratio is 77% (5% of limestone and 18% of anhydrous calcium sulphate). C$\bar{S}$A cements can be used as total replacement for Portland cement. The C$\bar{S}$A cement used is a commercial product from Vicat SA, Alpenat R^2.

The two other binders used are mineral additives: metakaolin (MK) and ground-granulated blast-furnace slag (GGBS). These two minerals cannot completely replace OPC but are used as additives. These two additives are characterized by their pozzolanic reaction. The pozzolanic reaction consumes calcium hydroxide (Portlandite), in contrast to the hydration of the clinker that produces it. Because Portlandite is responsible for the alkaline hydrolysis of plant fibres, pozzolanic additives appear as interesting materials to reduce the alkalinity of the cementitious matrix. The metakaolin used is a commercial product named Argicem, supplied by Argeco Développement. It has been used for substitution rates of 15 and 30%. The GGBS was supplied by the company Ecocem, and used at substitution rates of 30 and 60% of the OPC.

The main chemical and physical characteristics of the different binders used are given in Tab. 1. A laser diffraction particle size was performed on these four mineral binders. The granulometric curves obtained are provided in Fig. 1.

Tab. 1: Chemical and physical characteristics of the cementing materials.

Name	**ordinary Portland cement**	**calcium sulfo-aluminate cement**	**Metakaolin**	**Ground-granulated blast-furnace slag**
Abbreviation	**OPC**	**C$\bar{S}$A**	**MK**	**GGBS**
SiO$_2$ (%)	21,7	8,16	68,76	37,4
Al$_2$O$_3$ (%)	4,1	18,22	27,01	10,9
CaO (%)	66,9	43,60	1,04	43,9
Fe$_2$O$_3$ (%)	0,3	7,63	2,56	0,7
MgO (%)	0,7	0,77	0,18	6,5
TiO$_2$ (%)	0,2	0,99	0,44	0,5
K$_2$O (%)	0,10	0,21	1,21	0,24
Na$_2$O (%)	0,01	0,13	0,44	0,34
SO$_3$ (%)	2,7	15,24	-	0,1
Loss on ignition (%)	2,8	3,8	0,72	< 1,5
Fineness (cm^{-2}.g^{-1})	4250	4500	6270	4450
Density (g.cm^{-3})	3,05	2,97	2,30	2,90

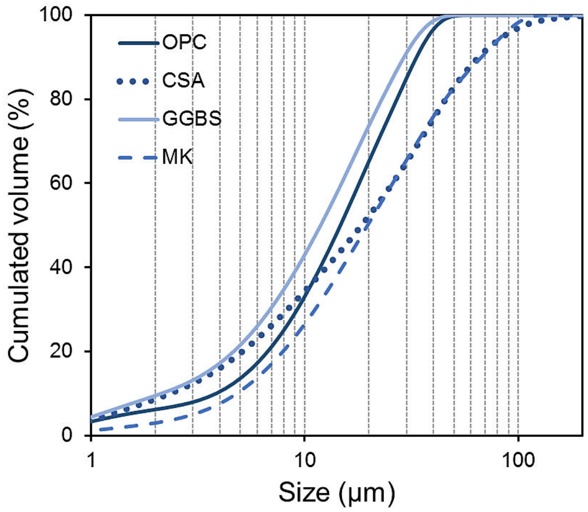

Fig. 1: Particle size distribution of binders.

Other materials

A high range water reducer superplasticizer based on polycarboxylates was added with a ratio of 1,0% relative to the mass of binder (i.e. 0,30% solids) to provide a better workability in the fresh state.

In addition, a viscosity-modifying agent (VMA) based on a high-molecular weight bio-polymer was added to the mortars with a ratio of 0,50% relative to the mass of binder (i.e. 0,03% solids) to avoid the segregation phenomenon between the paste and the aggregates

An alluvial sand with grain size 0/4 mm was used. This sand presents a specific gravity of 2,69 g.cm^{-3}, an absorption coefficient of 0,30% and a fineness modulus of 2,10.

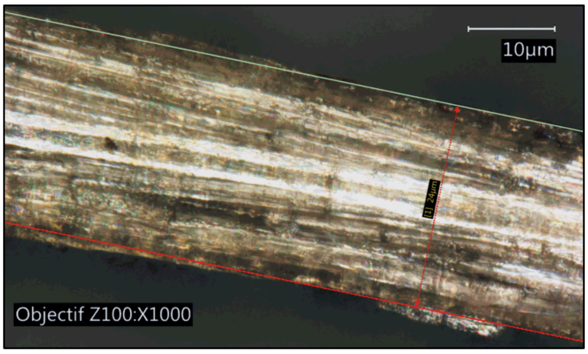

Fig. 2: Observation of a single flax fibre with a video microscope.

Flax fibres used were harvested in Normandy (France) in 2014, cut at a constant length of 12 mm and provided by Vandecandelaere Company (Depestele Group), specialized in flax farming and scutching (Figure 1a). These raw flax fibres present a real density of 1,52 g.cm^{-3}, and a mean diameter of 14,66 ± 2,95 µm. The water absorption of the flax fibres after 24 hours of immersion is 132,4 ± 4,2%. A video-microscope observation of a flax fibre is given in Fig. 2. This value was used for the correction of the effective water content for the mortars mix design.

2.2 Equivalent binder concept

Since the publication of the French standard NF EN 206-1/CN on ready-mixed concrete, the cement-based mix-design method has been replaced by the concept of equivalent binder (B_{eq}). This parameter allows to take into account the activity of an additive, such as metakaolin, GGBS, limestone filler, etc. The amount of equivalent binder from the French standard is defined by the following expression:

$$\mathrm{B_{eq}} = \mathrm{C} + \mathrm{k} * \mathrm{A} \quad (1)$$

where B_{eq} is the amount of equivalent binder (kg.m^{-3}); C is the amount of CEM I cement (kg.m^{-3}); k is a factor which considers the activity of an additive; A is the quantity of the additive (kg.m^{-3}).

According to EN 206-1 standard, the coefficients k for metakaolin and GGBS are respectively equal to 1 and 0,9.

2.3 Mortars mix design

The respective proportions of the mortars components are detailed in Table 2. The effective water on equivalent binder ratio (W_{eff}/B_{eq}) was fixed to 0,51. An additional amount of water was added for take into account the water absorption of aggregates and flax fibres.

The amount of flax fibres was 1,0vol.% relative to the total batch volume. Not to change the theoretical batch volume when adding fibres, a saturated sand volume equal to the volume of saturated fibres was removed from the formulation.

After mixing, the mortars were cast in two layers into prismatic moulds (40x40x160 mm). To expel the air from the mixture, the moulds were subjected to 60 hits on a vibrating table after the pouring of each layer. The test pieces were demoulded 24 hours after manufacturing, and then placed controlled room at 20±1°C and > 90%RH.

Tab. 2: Mortars composition (kg.m^{-3}).

Name	CM	OPC-100	CSA-100	MK-15	MK-30	GGBS-30	GGBS-60
Cement (OPC)	508,6	508,6	-	432,3	356,0	356,0	203,4
Additive	-	-	508,6	76,3	152,6	169,5	339,1
Water	254,3	254,3	254,3	254,3	254,3	254,3	254,3
Sand	1525,7	1446,7	1433,2	1424,9	1403,0	1423,6	1400,4
Superplasticizer	5,09	5,09	5,09	5,09	5,09	5,26	5,42
VMA	2,54	2,54	2,54	2,54	2,54	2,63	2,71
Flax fibres	-	15,2	15,2	15,2	15,2	15,2	15,2
Theoretical density (kg.m^{-3})	2300,8	2256,4	2242,8	2234,4	2212,5	2250,4	2244,3

The names of the tested mortars are as follows:

- **CM**: control mortar (non-fibre-reinforced) with 100% of ordinary Portland cement.
- **OPC-100**: FFRM with 100% of ordinary Portland cement.
- **CS̄A-100**: FFRM with 100% of calcium sulfo-aluminate cement.
- **MK-15**: FFRM with 15% of metakaolin and 85 % of ordinary Portland cement.
- **MK-30**: FFRM with 30% of metakaolin and 70 % of ordinary Portland cement.
- **GGBS-30**: FFRM with 30% of GGBS and 70 % of ordinary Portland cement.
- **GGBS-60**: FFRM with 60% of GGBS and 40 % of ordinary Portland cement.

3 TESTING METHODS

3.1 Workability of fresh mortars

The measurement of the workability of the different mortars was assessed with two testing apparatus. The first test consists in measuring the flow time using a testing device recommended by the French standard NF P18-452 (maniabilimeter). This test is used to estimate the dynamic workability of mortars. The apparatus consists of a compartment divided into two unequal volumes by a removable wall. The test measures the time taken for the mortar to flow from the large compartment in the small one under the influence of the imposed vibration.

The second test was performed with the flow table (EN 1015-3). The flow value is measured by the mean diameter (in two perpendicular directions) of a sample of the fresh mortar which was placed on the flow table tamper by means of a truncated conical mould, and given 15 vertical hits by raising the flow table and allowing it to fall freely from a height of 10 mm.

3.2 Compressive and 3-point bending tests

The mechanical properties of mortars were determined by implementing compressive and three point bending tests in accordance with the EN 196-1 standard. For each mix, four specimens were tested.

The compression test was implemented at a loading rate of 40 N.min^{-1}. In order to highlight the post-peak behaviour of flax fibre-reinforced mortars, the 3-point bending tests were displacement-controlled at a rate of 0.20 mm.min^{-1}.

3.3 Water accessible porosity and dry density

Water accessible porosity (WAP) of the hardened mortar specimens was calculated through vacuum saturation and with a hydrostatic balance according to the NF P18-459 standard at 28 days curing. For each mix, four specimens were tested.

The 'saturated surface dry' state of the specimens was obtained through vacuum saturation. Initially, the specimens were placed in a vacuum chamber in presence of silica gel in order to decrease the contact angle of the water of the pores and dry the specimens. After 4 h the water was introduced in the chamber so as the specimens got immersed and the vacuum was kept during additional 44 h. The WAP was obtained from the mass of the 'saturated surface dry' specimens measured in air (m_{air}) and in water (m_{water}), and the mass of specimens oven dried at 50°C (m_{dry}), using the following equation:

$$\mathrm{WAP} = \frac{m_{air} - m_{dry}}{m_{air} - m_{water}} * 100 \qquad (2)$$

From these three masses, it is also possible to estimate the dry density (ρ_d) of the samples, by using Eq. (3).

$$\rho_d = \frac{m_{dry}}{m_{air} - m_{water}} * \rho_{water} \qquad (3)$$

with ρ_{water}, the water density (kg.m^{-3}), used for the hydrostatic weighing.

4 FIGURES AND TABLES

4.1 Fresh state properties of mortars

The fresh properties of the mortars are shown in Table 3. The addition of flax fibres in the mortars seems to significantly increase the air content and consequently cause a significant reduction in their density. The control mortar had a low air content of 1,81 ± 0,63%, while the air content of the FFRMs is between 6,28 ± 0,79% and 8,14 ± 1,29%, i.e. an increase in air content of about 250 to 350%. However, variations in air content between the different mixtures of FFRMs remain insignificant. This increase in air content was also highlighted by other authors [Madsen 2009, Pickering 2016]. It is mainly attributed to the low ability of plant fibres to compact. The increase in void content could also be explained by an inadequate compaction process of the specimens [Aziz 1981].

Tab. 3: Properties of fresh mortars.

Mix	Fresh density (kg.m^{-3})	Air content (%)	Flow time (s)	Relative flow (%)
CM	2256 ± 15	1,81 ± 0,63	1,4 ± 0,3	174,5 ± 7,8
OPC 100	2119 ± 18	6,56 ± 0,54	22,9 ± 1,6	14,0 ± 1,4
CSA 100	2071 ± 14	7,67 ± 0,64	18,3 ± 3,5	19,3 ± 0,4
MK 15	2053 ± 29	8,14 ± 1,29	18,4 ± 1,2	17,5 ± 4,9
MK 30	2074 ±17	6,28 ± 0,79	23,8 ± 2,6	14,5 ± 4,9
GGBS 30	2082 ± 11	7,46 ± 0,49	7,2 ±1,3	38,3 ± 4,6
GGBS 60	2093 ± 29	6,76 ± 1,30	8,6 ± 2,3	31,5 ± 2,1

Moreover, the addition of flax fibres in the mortars also significantly affects their consistence. The control mortar has a very fluid consistency. Indeed, with the maniabilimeter, a flow time of 1,4 + 0,3 seconds was measured and a relative flow of 174,5 ± 7,8% with the flow table test. The OPC100, which is a cement-based FFRM, has a very firm consistency. The values obtained with this mortar for the two workability tests are respectively 22,9 ± 1,6 seconds and 14,0 + 1,4%. These rheological disturbances are mainly attributed to the high demand for water due to the high-water absorption capacity of flax fibres (up to 130 % of dry fibre mass) and their high specific surface area [Page 2016].

The CS̄A-100, MK-15 and MK-30 mortars also have a very firm consistence, similar to OPC-100 mortar (Table 3). However, the substitution of cement by 30 and 60% of GGBS seems to improve the workability of FFRM. With 30 and 60% of GGBS, the flow time was reduced by respectively 69 and 62%, relative to the OPC-100 mortar. Other authors have also observed an improvement in the workability of mortar and concrete when substituting cement with GGBS. This is attributed to the slow early hydration of GGBS and its reduced demand for water [Ling 2014, Tamilarasan 2012].

4.2 Compressive and flexural strengths

The compressive strength of mortars after 7, 28 and 90 days curing are shown in Figure 3. It can be noted that the flax fibres cause a reduction in the compressive strength. Indeed, the compressive strength at 28 and 90 days of the OPC-100 mortar decreased by respectively 13 and 7%, relative to the control mortar (CM). CS̄A-100 mortar, in which 100% of Portland cement was replaced by CS̄A cement, exhibits lower compressive strengths. For MK and GGBS mortars, compressive strengths at 7 and 28 days of curing are below the OPC-100 mortar, with 100% Portland cement. However, after 90 days of curing, the compressive strengths of MK mortars are almost equal to OPC-100, and those of GGBS mortars are even higher. This is due to the pozzolanic reaction which has a slower kinetics than the hydration reaction.

The flexural strength of mortars after 7, 28 and 90 days curing are shown in Figure 4. It is noted that for the same cement-based matrix (CM), the addition of flax fibres (OPC-100) increases the flexural strength of mortars: from 21% at 28 days to 25% at 90 days. As observed for the compressive strength, CS̄A-100 mortar exhibits lower flexural strength compared with OPC-100. However, an increase in the flexural strength with the curing time is observed for this mortar as well. For MK and GGBS mortars, the flexural strength also increases with the curing time. However, this increase in strength is much less than for the compressive strength. Thus, the higher the substitution rate of cement is, the lower the flexural strength is. This could be due to a change in the fibre/matrix interface. The 100% Portland-cement matrix could provide good short-term adhesion (at 7 and 28 days). Indeed, it is observed that the flexural strength at 28 days of the mortars OPC-100, MK and GGBS are relatively close, although it decreases with the increase of the substitution rate of Portland cement. The difference in flexural strength between OPC-100 and mortars MK and GGBS is 90 days. It has been seen in the literature review that in the long-term, an increase in maximum flexural strength was observed with plant-fibre-reinforced cementitious composites due to fibre mineralisation in contact with the cement matrix [Toledo Filho 2000].

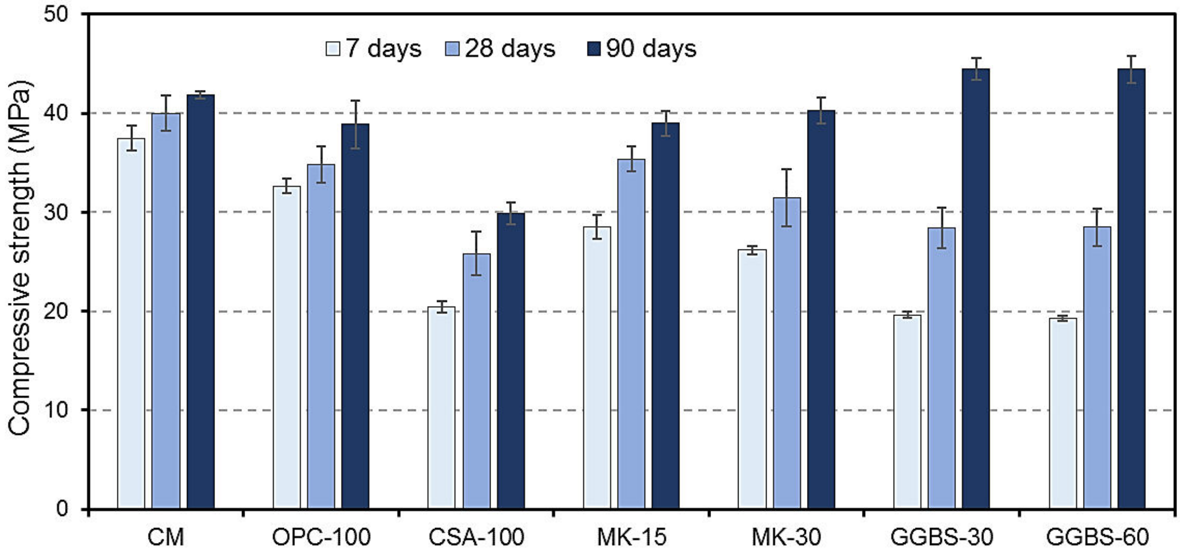

Fig. 3: Compressive strength of mortars after 7, 28 and 90 days curing.

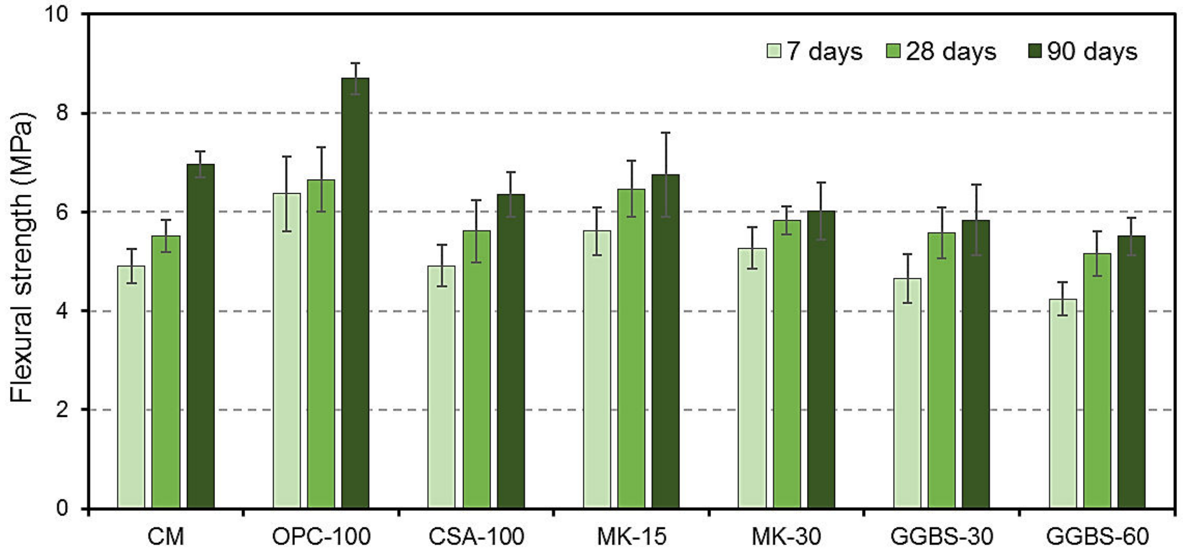

Fig. 4: Flexural strength of mortars after 7, 28 and 90 days curing.

This could mean that when the content of mineral additives (MK or GGBS) increases, the mineralisation phenomenon is reduced, which limits the increase in maximum flexural strength in the long-term.

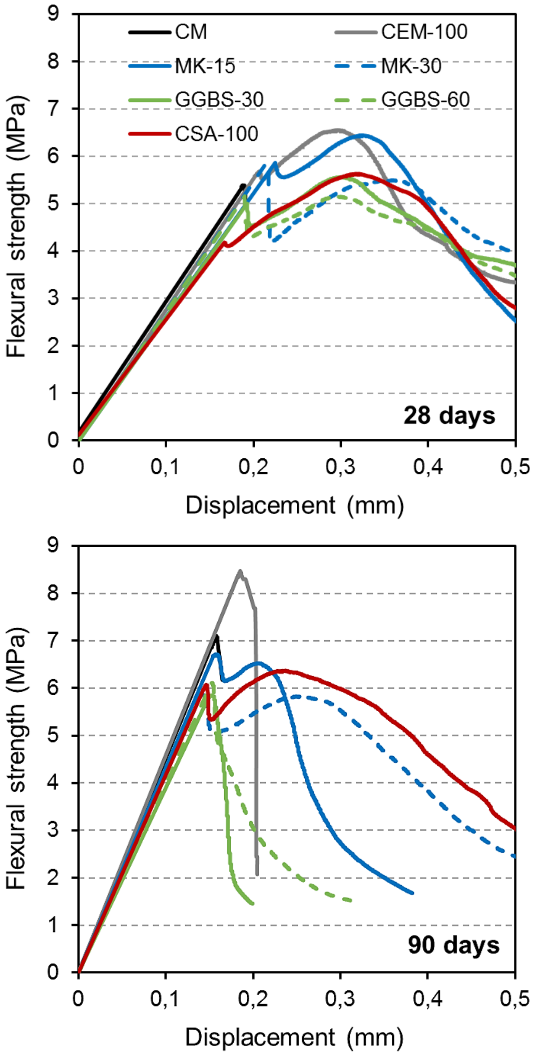

Fig. 5: Flexural strength vs displacement curves of mortars after 28 and 90 days curing.

Figure 5 shows the stress-displacement curves of the 3-point bending tests after 28 and 90 days of cure. The addition of flax fibres to the mortar prevents brittle fracture and induces a pronounced ductile behaviour. Note that after 28 days curing, the first accident on the strength-displacement curves (Figure 5) of the cement-based reinforced mortars (CEM-100, MK and GGBS) occurs at a stress level identical to the resistance of the unreinforced mortar (CM), except the CS̄A-100. After 28 days of curing, the FFRCs show relatively high and similar toughness, whatever the binder used.

However, after 90 days of curing, the CEM-100 mortar exhibits a high flexural strength but no toughness. This agrees with the results observed by other authors [Toledo 2000]. The loss of toughness is associated with the degradation of the flax fibres in contact with the highly-alkaline cementitious matrix; while the increase in flexural stress is probably due to mineralisation of the flax fibres. CS̄A cement appears to be the most effective binder to maintain a high toughness, and thus limit the degradation of flax fibres. Metakaolin also appears to be relatively effective. It is also noted that the higher the substitute ratio is, the higher is the toughness. However, the use of GGBS does not appear to be effective in limiting the fibre degradation cause a very low tenacity is observed, even with 60% GGBS. Toledo et al. have also observed that the GGBS do not allow any reduction in plant fibre degradation [Toledo Filho 2003]. The authors attribute this result to the insufficient reduction in the alkalinity of the interstitial solution.

4.3 Water accessible porosity and dry density

The water accessible porosity (WAP) and the dry density of hardened mortar specimens were measured by hydrostatic weighing. The results of this test are summarized in Figure 8. The reference mortar (CM) has a relatively low porosity of about 13,4 ± 0,2%. It is noted that the porosity of the flax fibre reinforced mortars is much higher than the control mortar. This is consistent with the observations made about the air content of flax fibre-reinforced mortars. It thus appears that the greater the porosity of the composite is, the lower is the compression strength. The WAP is inversely proportional to the dry density. The compressive strength of mortars is higher when the dry density increases.

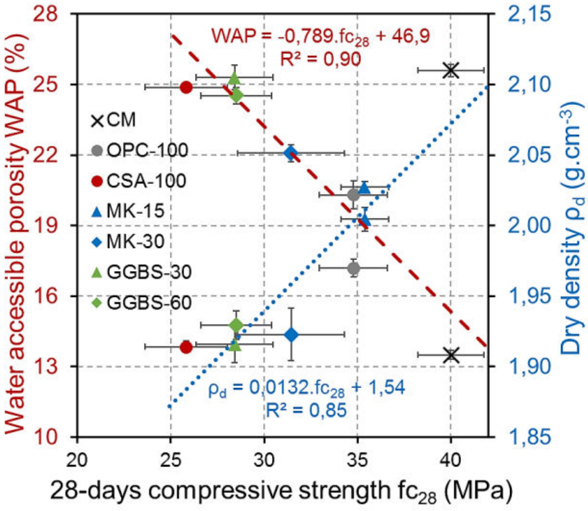

Fig. 6: Correlation between water accessible porosity, dry density and compressive strength.

5 CONCLUSIONS

This works has investigated a way to improve the durability of flax fibre-reinforced mortars using alternative binders. The following main conclusions were drawn:

- In fresh state, the use of alternative binders does not significantly affect mortar properties. However, the GGBS improves the fresh mortar workability.
- The additives influence the compressive strength of the mortars. C$\bar{S}$A cement results in a significant decrease, regardless of the curing period. With MK and GGBS, the 7-day strengths are lower due to the pozzolanic reaction. However, those at 90 days are equivalent to CEM-100 and even higher with GGBS.
- The use of alternative binders limit the degradation of the fibers between 28 and 90 days of treatment. Indeed, while with the CEM-100 mortar does not exhibit toughness at 90 days, the C$\bar{S}$A allows to maintain a high toughness. However, the GGBS does not appear to be effective in limiting this degradation.

6 REFERENCES

The authors wish to thank the co-founders, the European Regional Development Fund, the Normandy Region, as well as all partners and subcontractors of the BTONLIN project for their support, namely: the building construction company CMEG (project director), based in Bretteville l'Orgueilleuse (France), and the Teillage Vandecandelaere (Depestele), specialized in flax farming and scutching, based in Bourguebus (France).

7 REFERENCES

[Akers 1989] Akers, S.A.S.; Studinka, J.B.; Ageing behaviour of cellulose fibre cement composites in natural weathering and accelerated tests. International Journal of Cement Composites and Lightweight Concrete, 1989, Vol. 11, n° 2, p. 93-97.

[Aziz 1981] Aziz, M.A.; Paramasivam, P.; Lee, S.L.; Prospects for natural fibre reinforced concretes in construction. International Journal of Cement Composites and Lightweight Concrete, May 1981, Vol. 3, n° 2, p. 123-132.

[Bentur 2007] Bentur, A.; Fibre reinforced cementitious composites, 2nd Edition. Ed. Taylor & Francis, London, New-York, 2007.

[Chafei 2014] Chafei, S.; Khadraoui, F.; Boutouil, M.; Gomina M.; Optimizing the formulation of flax fiber-reinforced cement composites. Construction and Building Materials, March 2014, Vol. 54, p. 659-664.

[Chafei 2015] Chafei, S.; Khadraoui, F.; Boutouil, M.; Gomina, M.; Effect of flax fibers treatments on the rheological and the mechanical behavior of a cement composite. Construction and Building Materials, March 2015, Vol. 79, p. 229-235.

[Gram 1983] Gram, H.E.; Durability of natural fibres in concrete. Ed. Swedish Cement and Concrete Research Institute, Stockholm, 1983.

[Juarez 2007] Juarez, C.; Durán, A.; Valdez, P.; Fajardo, G.; Performance of "Agave lecheguilla" natural fiber in Portland cement composites exposed to severe environment conditions. Building and Environment, March 2007, Vol. 42, no 3, p. 1151-1157.

[Khazma 2011] Khazma, M.; Goullieux, A.; Dheilly, R.M.; Laidoudi, B. et al.; Impact of aggregate coating with a PEC elastomer on properties of lightweight flax shive concrete. Industrial Crops and Products, January 2011, Vol. 33, n° 1, p. 49-56.

[Kriker 2005] Kriker, A.; Debicki, G.; Bali, B.; Khenfer, M.M. et al.; Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate, Cement and Concrete Composites, May 2005, Vol. 27, n° 5, p. 554-564.

[Kriker 2008] Kriker, A.; Bali, A.; Debicki, G.; Bouziane, M. et al.; Durability of date palm fibres and their use as reinforcement in hot dry climates. Cement and Concrete Composites, August 2008, Vol. 30, n° 7, p. 639-648.

[Le Hoang 2012] Le Hoang, T.; Boutouil, M.; Khadraoui, F.; Gomina, M.; Mechanical and microstructural characterization of flax fibre-reinforced cement composite. In: Proceedings of the 11th Japan-Korea-France-Canada Joint Seminar on Geoenvironmental Engineering, Ed. Paralia, Caen, France, 2012, vol. 11, p. 131-136, ISBN 978-2-35921-006-4.

[Ling 2014] Ling, T.C.; Poon, C.S.; Feasible use of large volumes of GGBS in 100% recycled glass architectural mortar. Cement and Concrete Composites, October 2014, Vol. 53, p. 350-356.

[Madsen 2009] Madsen, B.; Thygesen, A.; Lilholt, H.; Plant fibre composites – porosity and stiffness. Composites Science and Technology, June 2009, Vol. 69, n° 7-8, p. 1057-1069.

[Merta 2013] Merta, I.; Tschegg, E.K.; Fracture energy of natural fibre reinforced concrete. Construction and Building Materials, March 2013, Vol. 40, p. 991-997.

[Mohr 2006] Mohr, B.J.; Biernacki, J.J.; Kurtis, K.E.; Microstructural and chemical effects of wet/dry cycling on pulp fiber–cement composites. Cement and Concrete Research, 2006, Vol. 36, n° 7, p. 1240-1251.

[Page 2016] Page, J.; Khadraoui, F.; Boutouil, M.; Gomina, M.; Experimental investigation on the treatment of flax fibers as reinforcement of a cementitious material. In: Proceedings of the 9th

Rilem International Symposium on Fiber Reinforced Concrete, Ed. RILEM, Vancouver, Canada, 2016, vol. PRO116, p. 870-878.

[Pickering 2016] Pickering, K.L.; Efendy, M.G.A.; Le T.M.; A review of recent developments in natural fibre composites and their mechanical performance. Composites Part A: Applied Science and Manufacturing, April 2016, Vol. 83, p. 98-112.

[Sedan 2007] Sedan, D. ; Etude des interactions physico-chimiques aux interfaces fibres de chanvre/ciment - Influence sur les propriétés mécaniques du composite. PhD Thesis. Université de Limoges, France, 2007.

[Sedan 2008] Sedan, D.; Pagnoux, C.; Smith, A.; Chotard, T.; Mechanical properties of hemp fibre reinforced cement: Influence of the fibre/matrix interaction. Journal of the European Ceramic Society, January 2008, Vol. 28, n° 1, p. 183-192.

[Sellami 2013] Sellami, A.; Merzoud, M.; Amziane, S.; Improvement of mechanical properties of green concrete by treatment of the vegetals fibers. Construction and Building Materials, October 2013, Vol. 47, p. 1117-1124.

[Soroushian 1994] Soroushian, P.; Shah, Z.; Won, J.P.; Hsu, J.W.; Durability and moisture sensitivity of recycled wastepaper-fiber-cement composites. Cement and Concrete Composites, January 1994, Vol. 16, n° 2, p. 115-128.

[Tamilarasan 2012] Tamilarasan, V.S.; Perumal, P.; Maheswaran, J.; Workability studies on concrete with GGBS as a replacement material for cement with and without superplasticizer. International Journal of Advanced Research in Engineering and Technology, December 2012, Vol. 3, n° 2, p. 11-21.

[Toledo Filho 2000] Toledo Filho, R.D.; Scrivener, K.; England, G.L.; Ghavami, K.; Durability of alkali-sensitive sisal and coconut fibres in cement mortar composites. Cement and Concrete Composites, April 2000, Vol. 22, n° 2, p. 127-143.

[Toledo Filho 2003] Toledo Filho, R.D.; Ghavami, K.; England, G.L.; Scrivener, K.; Development of vegetable fibre–mortar composites of improved durability. Cement and Concrete Composites, April 2000, Vol. 25, n° 2, p. 185-196.

[Winnefeld 2010] Winnefeld F.; Lothenbach, B.; Hydration of calcium sulfoaluminate cements — Experimental findings and thermodynamic modelling. Cement and Concrete Research, August 2010, Vol. 40, n° 8, p. 1239-1247.