

## EFFECT OF THE USE OF AUTOCLAVE ON BIO-CONSTRUCTION MATERIALS

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### Abstract

The paper discusses the use of autoclave as acceleration method for increasing the strength of bio-construction materials. Three mixes were studied, they were prepared in order to have a CaO/SiO<sub>2</sub> around 1. Hemp fibers were mixed with three different binder, Lime and silica fume mix (CaO/SiO<sub>2</sub> = 1), cement and silica fume mix (CaO/SiO<sub>2</sub> = 0,96) and cement, silica fume and lime mix (CaO/SiO<sub>2</sub> = 0,95). Two curing temperature (110°C, 130°C and 180°C) used. The results show an increase of the strength of lime and silica fume mix from 0,5MPa to 4,4Mpa after autoclave at 110°C. While the cement and silica fume has an increase from 0,8Mpa to 1,5Mpa after autoclave at 110°C. The same mixes at autoclave 180°C show smaller increase in strength than autoclave at 110°C.

### Keywords:

Hemp, lime, silica fume, cement, autoclave, compressive strength

## 1 INTRODUCTION

Concrete is among the least expensive materials we use around the world. However, the production of one tone of cement emits about 700-900 kg of CO<sub>2</sub> and other greenhouse gases (GHGs), which menace the stability of the planet.

In 2008, cement makers through World Business Council for Sustainable Development recognized the urgency to reduce CO<sub>2</sub> emissions from cement industries and requested the International Energy Agency (IEA) to evaluate long term options to lower the environmental impact. Improving energy efficiency, use of alternative fuels, use of alternative material to clinker and capture of CO<sub>2</sub> emissions were the main strategies considered. Where the main source of CO<sub>2</sub> in cement production comes from the decomposition of limestone and emits CO<sub>2</sub> (CaCO<sub>3</sub> → CaO + CO<sub>2</sub>).

Therefore, hemp concrete can represent a sustainable solution which respects the environment demands.

The compressive strength of hemp concrete is very low it is less than 2 MPa (1, 8-14), which is considered as a negative property for this type of concrete. Many factors play a role on the compressive strength if mixes prepared with hemp. The density is considered as a determinant factor in the increase of the compressive strength, higher density mix has higher compressive strength, mix with density 1,2g/cm<sup>3</sup> its in the order of 1,8MPa (1) while density of 0,8g/cm<sup>3</sup> give higher strength 0,8MPa (2).

The mix composition represent second factor which has a direct relation with the compressive strength, the presence of cement in mix increase the compressive strength (5). An increase of cement from 29 to 50%

(weight) doubled compressive strength (4). The third factors is the relative humidity has a role on the increase of the compressive strength, the mix with 50RH give higher strength 0,35MPa (7).

In order to ameliorate this property the use of autoclaved cycle can be used to increase the compressive strength. Whoever, the choice of curing temperature is governed with the change on the microstructure of binder. Changes can be occurred from CSH and CH to crystalline form tobermorite, which has a higher strength than both structure (CSH and CH) (16). The use of autoclave increase the compressive strength of mix and the higher strength was given for mix with quartz powder less than 2MPa at 190°C autoclaved (15).

Samri shows that hemp concrete presents good hygie properties with comparison with other concrete and has a real economical heat comfort (17). Florence et al. Have shown that hemp concrete has a good thermal behavior which is related to the low thermal conductivity (3).

## 2 EXPERIMENTAL AND TESTING PROGRAM

### 2.1 Materials

Hemp from Urika, three type of binder lime Tradical 98 compose of 92,5 of CaO, cement CME52.4 compose from CaO (64%) and SiO<sub>2</sub> (29.4%), silica fume type S95 DS from Condensil, *Superplasticizer* Adefor 2003 LOM, content from 22% of solid.

Table 1 shows the chemical composition.

Tab. 1: chemical composition of materials

	CaO (C)	SiO <sub>2</sub> (S)
Lime Tradical 98	92.5 %	
Silica fume		95 %
Cement	64 %	29.4 %

2.2 Test procedures

Materials

Three mixes were studied, they were prepared in order to have a CaO/SiO<sub>2</sub> around 1. Hemp fibers were mixed with three different binder, Lime and silica fume mix (CaO/SiO<sub>2</sub> = 1), cement and silica fume mix (CaO/SiO<sub>2</sub> = 0,96) and cement, silica fume and lime mix (CaO/SiO<sub>2</sub> = 0,95). Two curing temperature (110°C and 180°C) used.

Table 2 shows the composition of mixes used in the study, the quantities were calculated for 1M3. The water content was optimizing in order to have workable paste.

Tab. 1 : Composition of mixes

	Hemp	Lime	Cement
Cement	116	0	286
Lime	116	286	0
Lime + cement	116	100	140

The quantity of superplasticizer is 2% of the binder; the water was recalculated as the Superplasticizer has 78% of water. Mixer of 20 liter was used.

Mix proportions and concrete mix design

Samples were casted in cylindrical mold 11\*22cm, each sample was casted using 6 increments, using 50N for compacted each one. Samples were conserved at 25°C and 50% of relative humidity (RH) for 24h, and then samples were placed in autoclave for 24h at 30°C. Samples were put in autoclave at wanted temperature.

Autoclave cycle

Three temperatures were used in this study, 110°C, 130°C and 180°C, the speed used for heating is 60°C in 1hour, then the temperature is stabilized for 6h at the curing temperature. Figure 1 shows the temperature cycle of autoclave.

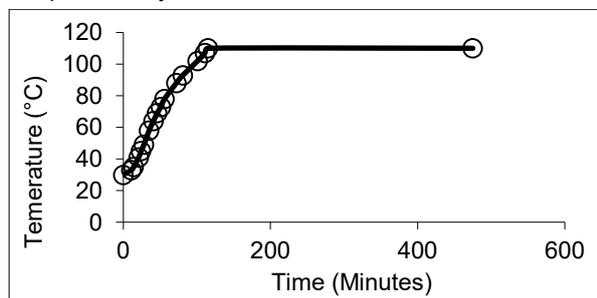


Figure 9: Temperature cycle used by autoclave at 110°C

Figure 2 shows the temperature and the pressure cycle used for autoclave at 180°C. the figure shows two curves, the temperature was noted at the left (in black) and the pressure at the right (in red).

After the cycle the samples were conserved at 50°C and the mass was measured each day until the stabilization, where the mass loss is inferior to 1%.

Mechanical test

MTC machine was used for mechanical test, with 100N/sec speed.

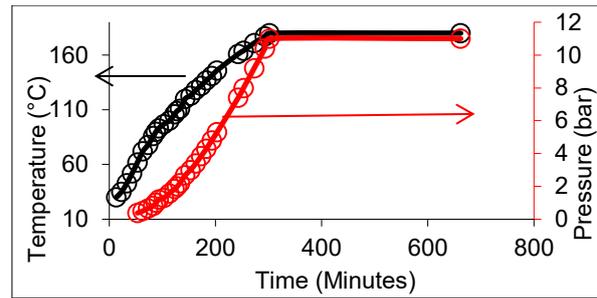


Figure 10: Temperature and Pressure cycle used for autoclave at 180°C

3 RESULT AND DISCUSSIONS

3.1 Density

The initial densities of mixes (after demolded) is reported in table 3, the mixes where the lime was used show higher density than which of cement.

Tab. 2: Densities of mixes used

	Density (g/cm <sup>3</sup> )
Cement + Silca Fume	0.90 ± 0.02
Cement + Lime + Silcia Fume	1.10 ± 0.05
Lime + Silca Fume	1.18 ± 0.02

Figure 3 show the mass loss as a function of conservation time. The mixes autoclaved at 180°C show mass loss stabilization after 15 days in 50°C where mixes at 110°C show a stabilization after 15 days, this can be related to the hydration of binder is faster for mixes at 180°C than at 110°C.

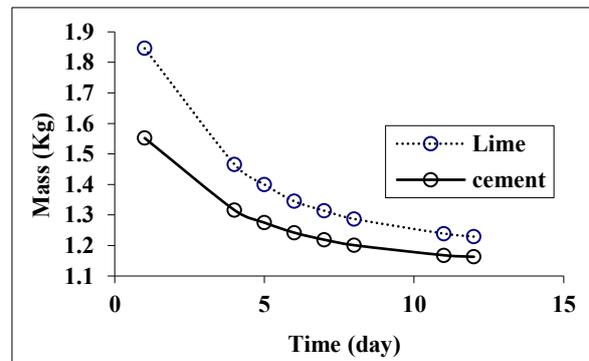


Figure 11: Mass loss as a function of mix and time

3.2 Mechanical tests:

Non autoclaved mixes

Samples were tested after 15 days conservation on 50°C RH. Figure 4 shows the stress train curves for the non-autoclaved mixes, cement, cement + lime, and lime. Cement mixes show higher compressive strength (0,8MPa) than other mixes, lime (0,5MPa) and lime + cement (0,7MPa).

Stress strain curve of cement mix and cement lime show similarity in behavior, it suggested that it comes from the composition, where the cement quantity is comparable thus the hydration product of cement can govern the mechanical behavior. The lime curve shows a lower value of compressive strength which comes from the formation of CaOH which has lower strength than CSH (which comes from cement hydration).

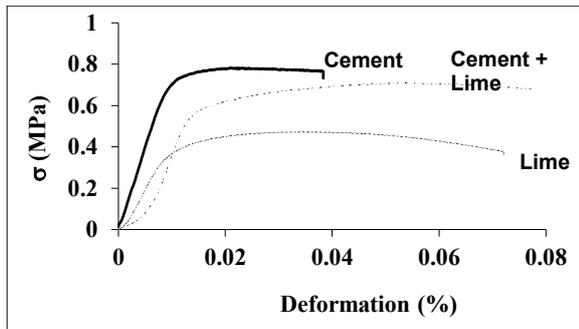


Figure 4: Stress Strain curve of non-autoclaved samples

Table 5 shows the compressive strength and the modulus of elasticity of non-autoclaved mixes.

Tab. 5: Compressive strength and modulus of elasticity of non-autoclaved mixes

Mix	Compressive strength (MPa)
Cement	0.78
Cement + Lime	0.71
Lime	0.47

**Autoclaved mixes at 110°C:**

Figure 5 shows the stress strain curves of autoclaved mixes at 110°C, lime mix show higher strength (4,4 MPa) then lime and cement mix (2,8MPa) and the lower strength is done for cement mix (1,5MPa) see table 6. It supposes that the higher strength of lime mix is coming from the reaction between CaOH and SiO2 to form tobermorite which has a higher strength than CH and CSH.

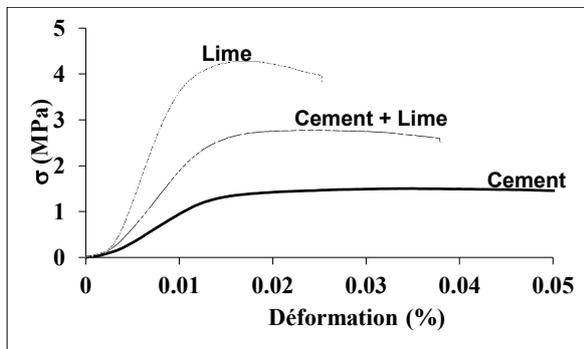


Figure 5: Stress Strain curves of autoclaved mixes at 110 °C

Table 6 shows the compressive strength and the modulus of elasticity of autoclaved mixes at 110°C. The strength values of autoclaved mixes are higher than non-autoclaved mixes.

The strength for autoclaved cement mix is 2 time higher than non-autoclaved one, while autoclaved lime mix shows 10 time higher than non-autoclaved one. The modulus of elasticity of lime mixes is higher for autoclaved mixes than non-autoclaved mixes while it is at the same range for cement mix.

Tab. 6: Compressive strength and modulus of elasticity of autoclaved mixes at 110 °C

Mix	Compressive strength (MPa)
Cement	1.47 ± 0.04
Cement + Lime	2.80 ± 0.03
Lime	4.35 ± 0.27

As a result the autoclaved is good tool to increase the strength of mixes where the lime is present.

**Autoclaved mixes at 130°C**

Figure 6 shows stress strain curves of autoclaved cement and lime mixes at 130°C. The lime curve shows high ductility than cement mix and lower strength. Table 7 shows compressive strength and modulus of elasticity of autoclaved cement and lime mixes.

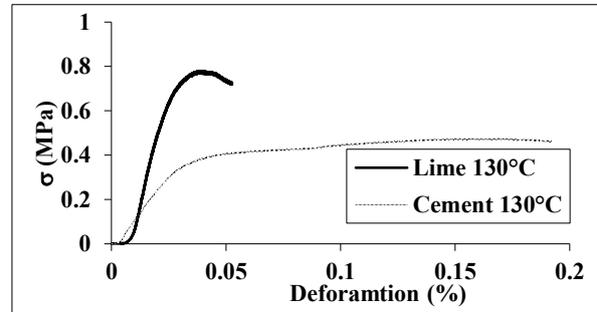


Figure 6: Stress Strain curves of autoclaved mixes at 130 °C

Tab. 7: Compressive strength and modulus of elasticity of autoclaved mixes at 130 °C

Mix	Compressive strength (MPa)
Cement	0.96 ± 0.13
Lime	0.79 ± 0.40

**Autoclaved mixes at 180°C**

Figure 7 shows the stress strain curves of autoclaved cement and lime mixes at 180°C, both curves show same behavior. Table 8 shows the compressive strength and modulus of elasticity of autoclaved cement and lime mixes at 180°C. Cement mix show two time increase in compressive strength (from 0.72 MPa to 1.8 MPa) while lime mix shows five time increase in compressive strength (from 0.33 MPa to 1.7 MPa).

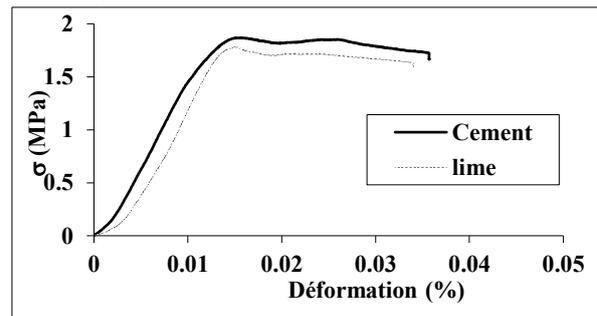


Figure 7: Stress Strain curves of autoclaved mixes at 180 °C

Tab. 8: Compressive strength and modulus of elasticity of autoclaved mixes at 180 °C

Mix	Compressive strength (MPa)
Cement	1.80 ± 0.15
Lime	1.68 ± 0.11

**4 CONCLUSION:**

Figure 8 show a summary of autoclaved results for cement and lime mixes at 110°C, 130°C and 180°C. Autoclaved lime mix at 110°C shows higher compressive strength while autoclaved mixes at 130°C

show the lower strength. The higher strength can be the result of the formation of more tobermorite in the mix which has higher strength than CSH and CH.

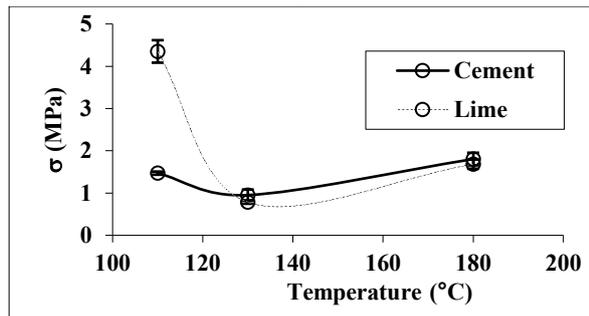


Figure 8: Summary of autoclaved result for cement and lime mixes

## 5 ACKNOWLEDGMENT:

This work was supported by the ENTPE, Lyon France within a post doc position, collaboration with Laurent Arnaud.

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