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INVESTIGATION OF THE MECHANICAL PERFORMANCE AND WEATHERING OF HEMP CONCRETE

M. Sonebi*[1], S. Wana[1], S. Amziane[2], J. Khatib[3]

[1] Queen's University Belfast, School of Planning, Architecture and Civil Engineering, Belfast, UK
[2] Université Blaise Pascal, Institut Pascal, BP 20206, Clermont-Ferrand, France
[3] 1Faculty of Science and Engineering, University of Wolverhampton, Wulfruna Street, Wolverhampton, UK

*Corresponding author; e-mail: m.sonebi@qub.ac.uk

Abstract

Lime hemp concrete is a sustainable building material that combines hemp shiv and building limes. The construction industry is responsible of the use of non-renewable materials, fossil, fuels, and cement, which produce high emission of carbon dioxide. The aim of this paper is to investigate the effect mix composition and the size of specimen on the mechanical performance and weathering of hemp concrete. The compressive strength 7 days and 28 days of hemp concrete were measured. The results demonstrated that binder content, size of specimens and densities had a significant influence on the compressive strength at both ages. Additionally, the wetting and drying cycles had highlighted the influence of weathering experiments after 10 cycles of testing on mechanical and physical properties of hemp concrete.

Keywords:

Hemp shiv, Lime, compressive strength, weathering

1 INTRODUCTION

"Hemp" refers primarily to Cannabis Sativa L. (Cannabaceae) [Amziane 2013] originally, it came from Asia and cultivated crop for thousand years ago. The hemp shiv is a complex woody tissue from the xylem layer of the hemp stem. It is considered to encourage bio-diversity relative to other common agricultural products and can be considered to be an environmentally enhancing crop. Moreover, the use of stem as a building material had been world emerging and growing market for the construction industry.

The construction of hemp into building materials is relatively new which had been introduced in the early 1990's in some European countries. In fact, there are now several hundred hemp buildings in France and Canada, the materials carrying out for hemp building. They are non-load bearing materials which have its advantages on a low environmental friendly used in building construction of high embodied energy and CO_2 emission. Hemp is a very good natural insulation material and it has thermal conductivity, λ is very low. Comparisons between thermal conductivity and density were reported by Arnaud [2009] and the values were found to vary between 0.07 and 0.11 $W/m.K^{-1}$ for densities between 200 and 500 kg/m^3.

Hemp shives can be considered of one of the most interesting renewable materials. It is not only used for construction purposes, also for rope and cloth making. Hemp can be used for wall, floors and roofs which can be mixed with lime or other binders to build an insulating, breathing composite

It was reported that 60% of a hemp particle's volume is made up of air [Nguyen 2009], and estimate the dry density ranged between 50 kg/m^3 and 100kg/m^3 [Elfordy 2007]. This high porosity leads to a hemp fibre being able to absorb up to 4 times its own dry mass in water over 48 hours [Nozahic 2012, Sonebi et al., 2013]. This ability to absorb may result in competition for water, between the binder - which requires it for hydration, and the shives, which could disrupt the mechanical abilities of the hemp concrete. Consideration must be given to this process when designing mixes. At present there is no standard for mix designs to serve as a guide for expected compressive strength results, but some researchers have tabulated their mix proportions for their results [Arnaud 2011], [Nguyen 2009] and [Murphy 2010]. Different mix proportions can be used for different purposes, for example a mix for a lime/hemp render would have lower hemp fibre content in order to achieve a smooth finish.

The objective of this investigation is study the effect of mix composition and the size of specimen on densities and the compressive strength at 7 days and 28 days and also on the weathering (drying and wetting).

2 MATERIALS, MIX PROPORTION AND TEST METHODS

2.1 Materials used

The Hemp Shiv used in the experimental work is called Tradical® HF. The amount of one bag is 20 kg was approximately 200L. Tradical HF® is a hemp fibre to be mixed with four binders: Tradical HB, Vicat Prompt cement, metakaolin (MK) and ground granulated blast-firnace slag (GGBS). These binders were used to produce a hemp concrete that can be used for walls, roof insulation and flooring.

Tradical® HF is a hemp aggregate made from the inner woody core of the hemp plant's stem. Hemp is chopped, graded and de-dusted to give a natural, sound and breathable product.

Tradical® HB has already used by several researches for making hemp concrete [Boutin 2005, Evrard 2008]. It is a special lime binder based on aerial lime (75%), hydraulic binder (15%) and pozzolanic binder (10%).

The mixes investigated were prepared with Tradical® HB specified by BS EN 459, Vicat Prompt cement, GGBS specified by BS EN 15167-2, and MK considered as a Class N Pozzolan under ASTM C-618.

Vicat prompt cement has been used as a mix hemp binder which is a rapid setting and quick hardening of natural cement. It is considered that this natural cement is hydraulic binders which are suitable to be used for sustainable building , thus this also relate with to hemp concrete construction. The chemical properties of Vicat prompt are shown in Table 1.

Metakaolin is supplied by Burgess optipozz. It is well known that the material is a highly reactive. It classified as 'highly reactive metakaolin' because working characteristic. The Specific surface area of GGBS and metakaolin were 600 and 13200 m^2/kg.

Tab. 1: Chemical properties of Vicat lime binder

Chemical Properties	
Characteristic	Average Value (%)
Silica (expressed as SiO_2)	18.4
SO_3 content	3.2
Loss on Ignition	9.4
Insoluble content	3.2
Al_2O_3/$Fe2O_3$ ratio	2.3

2.2 Mix composition

The mix composition used and specified for different application; walls and floor are listed below:

- Hemp-Lime (THB) – Mix A & B (Wall) and Mix C (Floor)
- Hemp- Vicat (VPC) - Mix A & B (Wall) and Mix C (Floor)
- Hemp – Metakaolin (Low and High Metakaolin with 20% and 50% add water)
- Hemp Lime (THB) – GGBS

2.3 Method of sample preparation

Before mixing, the hemp shiv aggregates were placed into the oven at 60°C drying oven for 24 hours. The materials were taken out in the next day and leave it for 20 min which allow cooling down. In the total, six mixes were prepared in the laboratory using a Hobart mixer. The materials of mixing include hemp shiv, binders, citric acid (when Vicat prompt used) and water. The mixing procedure is listed below:

- Firstly, wipe the mixing bowl with wet tissue to moist the surface prior to mixing. Then, pour half of the amount of hemp shiv and presaturation of 65% of water is gradually pour at regular interval for 2.5 minutes
- Half of the remaining portion of hemp shiv is added into the mixer and binder is divided into two pour into the mixing bowl. This to ensure the water/lime ratio is constant throughout all the samples. Then, continue mixing again for another 2.5 minutes with 35% of water.
- In the middle of the time elapsed, some of the hemp concrete mixes are sticking on the surface of the bowl. Therefore, scrap the excess of hemp concrete with spatula blade to mix it well with the binders.
- The samples were mixed in total of 5 minutes. After mixing was completed the specimens were transferred into the 100 or 50 mm cubes.

In order to prevent from excessive loss of water due to evaporation, the specimens in the mould was covered with plastic cling. Lastly, once the casting is done the specimens are stored in the control room of 20±2 ˚C and its relative humidity is about 55 to 65%. Demoulding is carried out after 3 days of casting.

2.4 Testing methods

Before crushing cubes, the densities were measured. The compressive test was performed on cubes 50 mm and 100 mm and each mix tested 3 cubes. The pressure on the specimens was applied in the same direction as compaction, by rate 0.4mm/min. Fig. 1 shows typical compressive failure on hemp concrete under axial load.

Fig. 1: Typical failure of hemp concrete under axial compressive.

Drying and wetting cycling (Weathering Test):

For this test, volume and weight changes of the specimens are to be determined. The volume and weight variations on air drying and water storage are measured on cube specimens having dimension of 100 mm.

After 3 days of casting, the specimens are cured in the control temperature room for 14 days. Firstly, the test procedure was to place the cubes in ventilated oven to dry at 40˚ C for 48 hours. Then, the mass was measured after 48 hours (drying state) and the specimens were placed in water bath for another 48 hours. The specimens are fully immersed at a room temperature of 20˚C. Basically, the drying and wetting masses of specimen are measured after 48 hours of the one cycle.

3 RESULTS AND DISCUSSION

3.1 Compressive strength

The compressive strength values were obtained on 50-mm cubes. Fig. 2 shows typical failure of the specimen deformed under loading. The sample is compressed when the load increased as the load been applied. This is due to an irreversible compaction of porous material and this compaction process is similar to what is observed for porous materials and other cellular solids [Zhang 1990, Gibson 1988].

The specimens in Fig 2 (left) has been referred as failure by the compressive strength, the crack can be seen due to crumbling under compressive loading. The cracks mostly appears run in vertical manners across the sample depends on the bonding of the hemp aggregate and binders.

Fig. 3 shows that after reaching a critical strength, Mix A continued to deform at uniform stress and demonstrated to have ductile failure.

Fig. 2: Comparison of samples before and after testing.

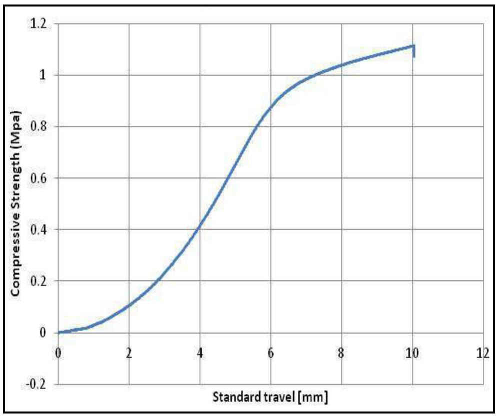

Fig. 3: A typical compressive strength of Hemp concrete.

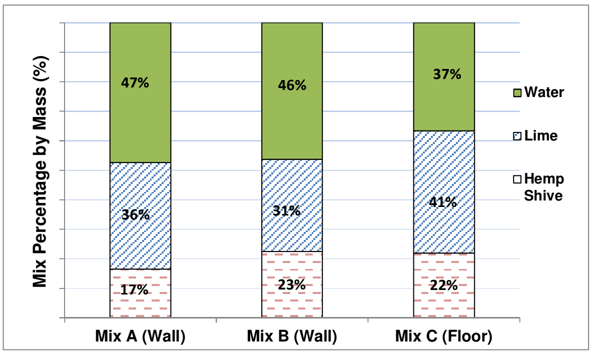

Fig. 4: Mix Proportions by percentage mass of THB and VPC lime binder.

Fig. 4 presents the mix proportions of THB and Vicat mixes and Table 2 summarised all results of compressive strengths. The results of compressive strength at 7 d and 28 d varied from 0.025 to 0.64 MPa, and 0.03 to 0.97 MPa, respectively.

As been observed, the Vicat prompt lime mixes had a lower compressive strengths compared to hydraulic lime THB. However, the compressive strength of hemp concrete depends on content of hemp shiv. Higher percentage of hemp, the lower compressive strength is. As results, 16% of hemp shives and 36% of lime binder with THB for sample mix A exhibited the highest compressive strength compared to those made with Vicat prompt (0.97 MPa vs. 0.26 MPa). Therefore, mix A with THB or Vicat prompt can be considered to be suitable for rigid foam of insulation material which the compressive strength required is ranged from 0.10 to 0.12 MPa.

Table 2: Results of density and compressive strength

	Density (kg/m^3)	f'c (MPa) 7 d	28 d
THB – A	402	0.64	0.97
THB – B	369	0.12	0.15
VPC – A	345	0.26	0.26
VPC – B	278	0.08	0.11
VPC – C	330	0.16	0.24
THB + GGBS	270	0.025	0.03
THB + MK 1	264	0.04	0.045
THB + MK 2	473	0.17	0.30
THB – MK3	411	0.20	0.38

The more binder content is, the higher the compressive strength as can be seen in Fig. 4 of mix A for wall by using 36% of THB lime had a great significant an increase of compressive strength compared to mix B.

The mix proportion of mixes made with GGBS and MK are presented in Fig. 5. The influence of replacement of lime by metakaolin and GGBS with THB lime based was also investigated (Tab. 2). One mix with GGBS and 3 mixes with MK were tested. The results of compressive strength of mix MK3 demonstrated the highest values of compressive strength at 7 and 28 d and the mix with GGBS exhibited the lowest compressive strength. As it can be seen, MK3 was made with 31% with metakaolin and it is the mix which indicated the best performance. The increase in MK percentage led to an improvement of compressive strength at 7 and 28 d (from MK 1 to MK3). Due to the fineness and large surface area of MK, the particles hastened the rate of hydration, which also produced a rapid development of strength [Sonebi et al. 2013].

Furthermore, the hemp lime concrete composition incorporating with MK and THB lime binders affected significantly the compressive strength at 7 d and 28 days. Hence, the THB binder made with metakaolin (MK3) clearly performs better than the other mix proportion, the compressive strength increased from 0.20 MPa at 7 d to 0.38 MPa at 28 days. The water content of mix MK3 was 47% compared to 52% for mix MK2.

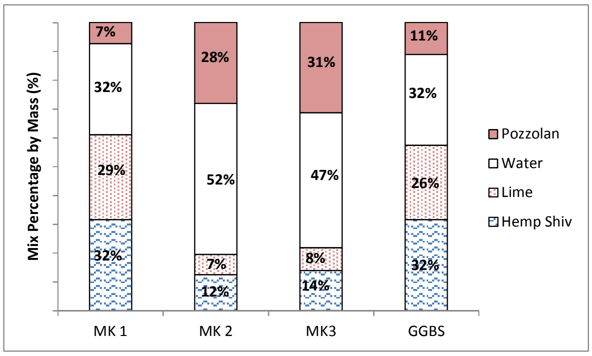

Fig. 5: Mix proportions by percentage mass of THB lime and pozzolans binder.

Variation of density

Another aspect influencing the results being considered is the relationship stress level and between compressive strength and density. The increase in compressive strength of hemp lime composition with THB and VPC lime binder relates to the higher density of the specimen (Fig. 6). It was noticeable improvement in specimen integrity comes along with increasing binder content as noted by [Bruijn. 2009].

Following specimens test made by THB binder and pozzolans are being compare, it appear low significant increase in compressive strength, which relates to high density (Fig. 6). Therefore, it can be observed generally that the mixes having higher densities had a higher compressive strength. The density and compressive strength are also two closely related parameters. As it was reported by other researchers the low compressive strength of hemp concrete is due to that low density [Sonebi et al. 2013]. However, high density will allow to have lower thermal performance of hemp concrete.

Effect size of specimen

This part of investigation was carried out on different moulds sizing with the same mix (THB Mix A and Mix B) and same curing conditions. The test specimens are made with 50 x 50 x 50 mm (MA50 and MB50) and 100 x 100 x 100 mm (MA100 and MB100) moulds.

It is clearly seen from Fig. 7 that the compressive strength of small size 50mm are almost twice stronger than those of size 100mm, particularly for Mix A. The hemp concrete based on THB binder (Mix B) of cube of 50 mm has a very low mechanical strength even after 28 days. In fact, the small size of Mix A led to higher compressive strength at 28 d (0.9 MPa).

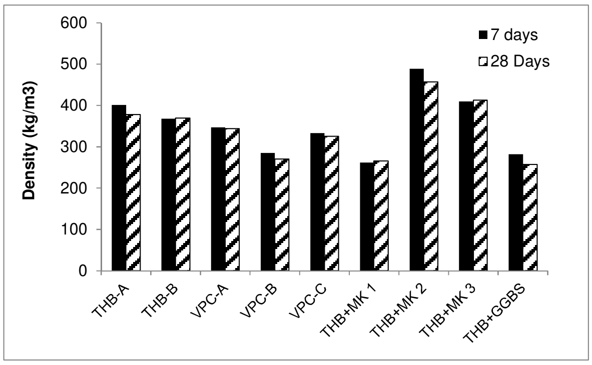

Fig. 6: Densities of Specimens for 7 and 28 days.

Therefore, THB binder combination with hemp shiv and water as a building material for walls appears to have increase significant results on compressive strength at 28 days. The mix A has 36% of THB lime binder compared to 31% for mix B. As expected, the THB lime binder content (36%) shown a higher compressive strength compared to Mix B.

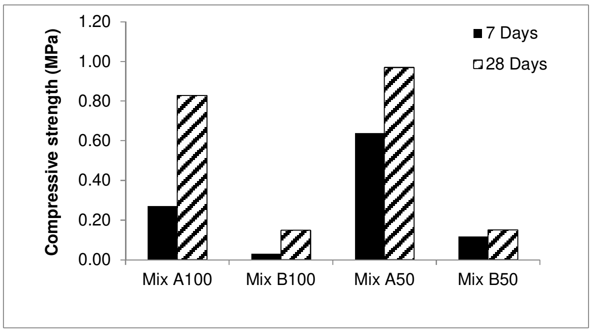

Fig. 7: Effect of the size of specimens on compressive strength (Mix A and MIX B).

3.2 Weathering

The purpose of this part of study is to investigate the influence of wetting and drying cycles on the variation mechanical performance and mass. Three type of hemp concrete mixture used for wall and floor were tested. During the experimental study, hemp-lime concrete is manufactured with THB binder in cubes of 100 mm size. The process of wetting and drying cycles took two months which equivalent to ten cycles, the density of the samples ranged between 270 and 550 kg/m^3 in which apparently commonly used in France for wall insulation.

Drying and wetting variations

Wetting and drying cycles of lime hemp concrete are used to simulate the natural ageing of the materials used in a building. The samples were kept at 40℃ in an oven chamber of drying process and exposed to full wetting cyclic in room temperature. The variations of mass loss of the samples were measured.

The rate of drying and wetting of the hemp lime concrete was monitored at regular interval over 60 days. Overtime, there was a rapid net mass variation as can be seen in Fig. 8 for Mix B. This has been influenced by the density of the specimens prepared have a small amount of lime binder content. Hemp shiv absorbed amount of water rapidly due to its highly porous of sample specimens. Thus, it led to destroy or damage the hemp structure and reduction in dimension of the specimens. This is due to water penetration into the gaps and flaws in the hemp structure during immersion of water of wetting cycles. It is roughly about 0.5 mm decrease from the original measurement after the drying and wetting of 10 cycles. As results, there was a reduction in density value with lighter specimens and higher porosity.

As it can be seen in Fig. 8, mix A presented a uniform pattern of mass variation. As regard, the densities of hemp concrete are slightly reduced about 12% from the initial mass. In case of denser hemp concrete, the water cannot be easily penetrated into the micro gaps inside inorganic matrix. Whereas, mix C has lower binder/hemp shiv ratio which lower down the hydration process and slight significant loss in densities. After 10 cycles of drying and wetting, it can be observed that Mix B resulted in the highest drop in the density.

Mechanical properties of weathering

Another objective of this paper is to determine the influence of weathering and non-weathering on the compressive strength of hemp concrete after ten cycles. The non-weathering is a process where after the wetting cycles then the compressive test are measured, whereas weathering is after drying cycle. The compressive strength values after conducting the weathering process was found to be in the range of 0.03 to 0.5 MPa (Fig. 9).

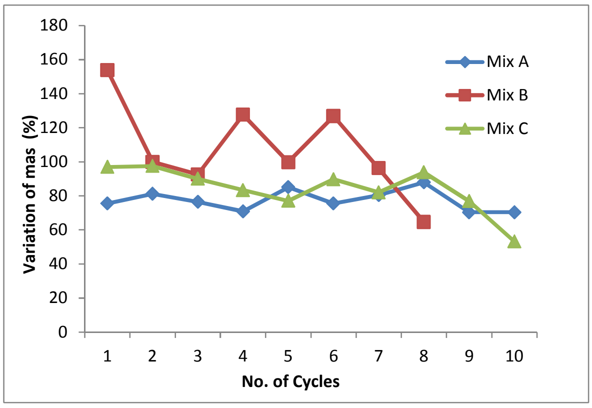

Fig. 8: Variation of mass of mixes A, B and C after 10 cycles of drying and wetting.

The reduction of compressive strength was approximately 53%, 81% and 46% for mix A, mix B and mix C, respectively. The biggest drop in compressive strength was for mix B. The weathering affected significantly the compressive strength after only 10 cycles. It can be noted than the compressive strength of mix A dropped from 1.11 MPa to 0.52 MPa after weathering and can be considered to have sufficient compressive strength (higher than 0.50 MPa) to be used for wall.

This reduction of compressive strength after wetting and drying can be attributed to the softening of the hemp concrete (mix rich with hemp shiv aggregates) and weakening of the interface zone between hemp shive fibres and binder, which can also led to an increase in the porosity. It was observed also after cycles, the water changed the colour and it may also some leaching materials.

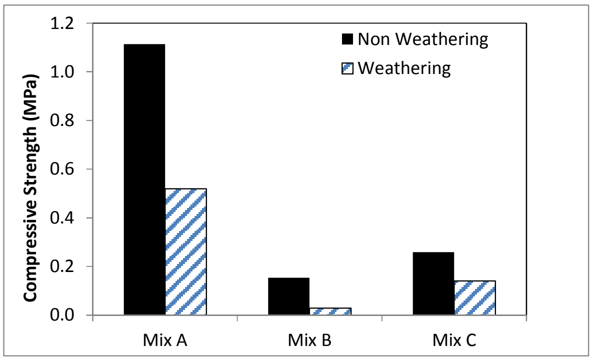

Fig. 9: Effect of wetting and drying of THB on compressive strength after 10 cycles.

4 CONCLUSIONS

This paper investigates the effect of type binder on the compressive strength and durability (resistance of weathering). The comparison included two commercial hemp-limes and pozzolanic materials metakaolin and GGBS.

Firstly, the type of binder affected significantly the compressive strengths. The commercial lime-binder THB exhibited the highest compressive strength at 28 days. The partial replacement of THB by GGBS led the lowest compressive strength followed by the metakaolin. The Vicat prompt lime binder exhibited a low compressive strength compared to THB binder. In fact, the high binder ratios are resulted to high compressive strength. Moreover, it can be concluded that the compressive strength of hemp concrete can be related densities. Higher density can lead to a high compressive strength. The nature failure of the hemp concrete under loading tends to compress with damage slight perpendicularly. Small size (50mm cube) of hemp concrete led to higher compressive strength compared to size 100-mm cubes.

Lastly, the weathering process was carried out for 10 cycles of drying and wetting. The compressive strength of weathering specimens were investigated and compared with the non-weathering specimens. It indicates that the weathering affected significantly the compressive strength which was dropped by 50% to 80%. Mix B exhibited the highest reduction of compressive strength. This can be attributed to the softening the hemp concrete, and the weakness the interfacial zone between hemp aggregate and binder and an increase in the porosity.

5 REFERENCES

[Amziane 2009] Amziane, S., Arnaud, L. Bio-aggregate based building materials: applications to hemp concrete. Location: London.

[Arnaud 2009] Arnaud L. In: Comparative study of hygrothermal performances of building materials 11th international conference on non-conventional materials and technologies (NOCMAT 2009). Bath, United Kingdom.

[Arnaud 2011] Arnaud, L., Gourlay, E., Experimental study of parameters influencing mechanical properties of hemp concrete, Construction of Building Material, 2011, Vol.28, pp. 50-56.

[Boutin 2005] Boutin, M.P.; Flamin, C.; Quinton, S.; Gosse, G.; Etudes des caractéristiques environnementales du chanvre par l'analyse de son cycle de vie. INRA, 2005.

[Brujin 2009] Brujin, P., Jeppsson. K., Sandin, K., Nilsson, C., Mechanical properties of lime-hemp concrete containing shives and fibres, Biosystem Engineering, 2009, Vol. 103, pp. 474 – 479.

[Elfordy 2008] Elfordy S, Lucas F, Tancret F., Scudeller Y, Goudet L., Mechanical and thermal properties and hemp concrete ("hempcrete") manufactured by a projection process, Construction and Building materials, 22, pp. 2116-2123.

Evrard 2008] Evrard, A.; Transient hygrothermal behaviour of Lime-Hemp Materials. PhD thesis. Université Catholique de Louvain, 2008

[Gibson 1988] Gibson L, Ashby M., Cellular solids: structures properties. Oxford, Pergamon Press, 1988.

[Nozahic 2012] Nozahic, V.; Amziane, S.; Torrent, G.; Saïdi, K., Design of green concrete made of plant-derived aggregates and a pumice–lime binder. Cement & Concrete Composites, February 2012, Volume 34, Issue 2, p. 231-241, ISSN 0958-9465.

[Nguyen 2009] Nguyen, T., Picandet, V.; Amziane, S.; Baley, C., Influence of compactness and hemp hurd characteristics on the mechanical properties of lime and hemp concrete. European Journal of Environmental and Civil Engineering, November 2009, Volume 13, Issue 9, pp. 1039-1050, ISSN 1964-8189.

[Murphy 2010] Murphy, F., Pavia, S., Walker, R., An assessment of the physical properties of lime hemp concrete. Location: Department Civil Engineering, Trinity College, Dublin, 2010.

[Sonebi 2013] Sonebi, M., Lachemi, M., Hossain, KMA., Optimisation of rheological parameters and mechanical properties of superplasticised cement grouts containing metakaolin and viscosity modifying admixture, Construction and Building Materials Journal, Vol. 38, No. 1, 2013, pp. 126-138.

[Sonebi 2013] Sonebi, M., Robinson, A., Amziane, S., "Influence of Presaturation Regime, Percentage of Lime and Compaction on the Performance of Hemp Concrete", Proceedings of First Int. Conference on Rheology and Processing of Construction Materials and 7th Int. RILEM Conf. on Self-Compacting Concrete, Paris, September 2013, CD 8p.

[Walker 2014] Walker, R., Pavia. S., Mitchell, R., Mechanical properties and durability of hemp-lime concretes, Construction and Building Materials, 2014, Vol. 61, pp. 340-348.

[Zhang 1990] Zhang J, Wong TF, Davis M.. Micromechanics of pressure-induced grain crushing in porous rocks, Journal Geophysic Research Vol. 95, pp. 341-352.