3rd International Conference on Bio-Based Building Materials

June 26th - 28th 2019
Belfast, UK

ADOBE SPECIMENS OF GREENLANDIC FINE-GRAINED ROCK MATERIAL

I.M.G. Bertelsen[1]*, L.J. Belmonte[1], L.M. Ottosen[1]

[1] Department of Civil Engineering, Technical University of Denmark, Brovej 118, 2800 Kgs. Lyngby, Denmark
*Corresponding author; e-mail: imgber@byg.dtu.dk

Abstract
Every year, glacial rivers in Greenland transport and deposit vast quantities of fine-grained rock material (GP). In the present study we characterise this raw material (GP) and evaluate whether it is possible to produce adobe bricks for a local production in an Arctic region such as Greenland. The raw material characterization included determination of the grain size distribution and the plastic properties. For enabling the production of adobe bricks, it was, based on these tested parameters, found necessary to add a fraction of a coarser gravel-size material (KG) in addition to the fine-grained rock material (GP). Small-scale prisms and cylinders for determination of the drying shrinkage behaviour and the mechanical performance of the composite material were produced containing 50/50 of GP and KG, respectively. Adobe bricks are often reinforced with fibres of natural or synthetic materials to improve the ductility of the composites, such as for example straw, however, in Arctic regions such materials are often a scares resource due to the existing type of vegetation. Therefore, we instead added fibres from discarded polyethylene fishing nets, which is a local waste material often present in coastal towns in Greenland. The addition of fibres from waste fishing nets to the adobe specimens resulted in enhanced drying shrinkage behaviour, post-crack performance and toughness for prisms when exposed to flexural loads.

Keywords:
Adobe bricks, fine-grained rock material, waste fishing nets, fibre reinforcement, local resources

1 INTRODUCTION

Earth-based materials such as adobe bricks are one of the oldest building materials and have been used for construction purposes since antiquity [Houben 1993]. The production of adobe bricks is relatively simple and environmental friendly, since it consists of filling moulds with moist earth-based materials, often with addition of a fibrous material, which are then left to dry [Pacheco-Torgal 2012]. As a result of the simple production method, adobe bricks are relatively cheap and, despite their expected low strength, can advantageously be used as interior building materials.

Previous studies have shown that these fine-grain rock materials, which are accessible in the entire Arctic region, can be successfully used as main raw material in the production of fired clay bricks [Bertelsen 2015; Belmonte 2016; Belmonte 2015]. Belmonte [Belmonte 2015] found that the characteristics of this raw material collected in Greenland is very similar to other marine clays found in North America and North Scandinavia. However, because of the low population density in Greenland, the construction of an actual brick work for a larger scale production of fired bricks is questionable. Therefore, the production of adobe bricks could prove to be a simple and cheap alternative in Greenlandic buildings and replace some of the imported construction materials. In this experimentally-based research program, we investigate the performance of Greenlandic fine-grain rock materials as the main raw material in adobe specimens.

Fig. 1: Fine-grained rock material (GP) from glacial rivers in Greenland

Fibrous materials are added to adobe bricks mainly for improving the mechanical post-crack performance and for controlling the crack formation induced by drying shrinkage deformations [Binici 2005; Quagliarini 2010; Pacheco-Torgal 2012].

Another locally available material is discarded fishing nets, which can be found in large piles at dumpsites in many coastal towns, see Fig 2. The fishing nets used in Greenland are typically made of polyethylene (PE) and there are currently no large-scale reuse/recycling options for the waste nets, which causes accumulation of the material at the dumpsites. The fibres used for adobe bricks are traditionally straw or other types of vegetable materials, which in this case could be replaced by PE fibres. With the addition of a non-biodegradable synthetic fibrous material such as PE, it would require improved waste management for the demolished adobe bricks, but on the positive side, a local waste fraction can be reused and the fibres don't have the risk of rotting inside the adobe material, which can be the case for some vegetable fibres [Pacheco-Torgal 2012].

Fig. 2: Discarded fishing nets piled up at the dumpsite in Sisimiut, Greenland

Besides being a waste management challenge, marine plastic litter, of which fishing gear is a considerable fraction, is a growing global challenge. The vulnerable Arctic environment is also increasingly affected due to climate changes, more regular access to the Arctic Sea route and sea currents from the North Atlantic, which carries a continuous supply of marine waste to the region [Bergmann 2015].

The focus in this research project is on the performance of adobe specimens made from locally available fine-grained rock materials (GP) near Nuuk, Greenland, and gravel (KG) with the addition of recycled fibres of polyethylene (R-PE) obtained from discarded fishing nets.

2 MATERIALS AND METHODS

2.1 Characterization of raw materials

The raw materials used for the adobe brick production were fine-grained rock material (GP collected near Nuuk, Greenland), as main matrix; gravel (KG) as stabilizer; R-PE fibres as fibrous materials and water as lubricant. Based on initial investigations of the raw material, it was observed that a coarse, stabilizing fraction should be added to the GP to obtain a satisfactory grain size distribution for the production of adobe bricks [Houben 1993]. Therefore, gravel 0-8 mm (KG) from Kallerup, Denmark, was collected and used in the production of adobe bricks. For practical reasons, the gravel was collected from a gravel pit in Denmark; however, gravel resources are common in Greenland, and a similar gravel fraction could likely by found locally. The grain size distribution for GP and KG was done in accordance with [CEN-ISO/TS-17892-4 2004] on bulk samples of the sand fraction by the sieve analysis and on the silt and clay fraction by the hydrometer analysis. The grain density for GP was determined by following the procedures in [CEN-ISO/TS-17892-3 2004]. For the test, a sample of 10 g dried at 105 °C was used. Organic matter was only present in very small amounts and was therefore not removed from the GP samples. The determination of the liquid- and plastic limit for GP was carried out in accordance with [CEN-ISO/TS-17892-6 2004; CEN-ISO/TS-17892-12 2004], respectively, on a non-dried remoulded GP sample. For the fall cone penetration test, a 60 g/60° fall cone was used.

2.2 Fibres from discarded fishing nets

The fishing nets used in Greenland are typically made of PE materials. In this study, monofilament R-PE fibres obtained by mechanical cutting of discarded fishing nets of similar types as the ones used in Greenland, were provided by the Danish recycling company, Plastix A/S. See Fig. 3.

Fig. 3: R-PE fibres from discarded fishing nets after being cleaned in tap water

The fibres have a length of 15 ± 9 mm and a diameter of 280± 30 µm. More details on the fibre characteristics are given in [Bertelsen 2019; Bertelsen n.d.]. Since the provided fibres contained some impurities from the fishing operation etc., we investigated the influence of these impurities by both using uncleaned R-PE fibres and R-PE fibres which were cleaned in tap water in the adobe production.

2.3 Production and testing of adobe bricks

Prior to the laboratory-scale production of the adobe bricks, several iterations regarding the mixture design and drying procedure were carried out to identify a good result.

Examples on specimens with 100% GP; and 50% GP and 50% KG, respectively, are shown in Fig. 4. As a result of the fine grain sizes of GP and the drying process (30 °C for 48 h), the specimens with 100% GP were shrinking to an extent that resulted in severe drying shrinkage cracks, see Fig. 4a. Regarding the specimens with the addition of 50% GP and 50% KG, only few and very fine drying cracks appeared on the surface as seen in Fig. 4b.

(a)

(b)

Fig. 4: Influence of mixture proportions on drying shrinkage: a) 100% GP; b) 50% GP and 50% KG

Not only was the content of fines playing a significant role with respect to the shrinkage behaviour, but also the drying temperature. The specimens were exposed to an accelerated drying process, so that the core of the specimens could be dry after a few days of drying. The drying was primarily done at different temperatures (20, 30 and 50 °C) for at least 48 h to examine the drying efficiency and the drying shrinkage behaviour. The best results were obtained when drying the specimens at 30 °C for 48 h inside steel moulds.

The production of the adobe specimens included the following steps: the raw materials (GP, KG and R-PE fibres) were primarily hand-mixed to ensure an even fibre distribution, whereupon the water was added under continuous mixing for 2 min in a Hobart-type paddle mixer. The mixture proportions were 1.0 : 1.0 : 0.22 for GP, KG and water, respectively. The water content was slightly increased with the addition of fibres to keep a constant workability of the mixture. The fibre content was added in weight fractions of up to 4.0wt% corresponding to approximately 9.2vol%.

Prism-like specimens measuring 40 x 40 x 160 mm^3 for a three-point bending test were produced in three replicated per mixture design. The specimens were cast in lubricated steel moulds and tested in accordance with [UNI/EN-196-1 2005]. The drying shrinkage and the dry bulk density were measured on the prisms after 48 h at 30 °C. Cylinders measuring 60 mm x 120 mm with no fibre addition and 1.0wt% of R-PE fibres were prepared for the uniaxial compression test, also in three replicated. The three-point bending test and the compression test were carried out in an Instron 6022 hydraulic testing machine with a displacement controlled load applied at a rate of 1 mm/min.

3 RESULTS AND DISCUSSION

3.1 Raw material characterization

Table 1 shows the plastic properties and the grain density of GP.

Table 1: Characteristics of fine-grained rock material (GP)

Natural water cont. w_{nat} [%]	Plastic limit PL [%]	Liquid limit LL [%]	Plasticity index PI [%]	Grain density [g/cm^3]
15.4	17.1	30.9	13.8	2.74

The plasticity index, PI, calculated in accordance with [CEN-ISO/TS-17892-12 2004] as the difference between the liquid limit (*LL*) and plastic limit (*PL*):

$$PI(\%) = LL - PL$$

The plasticity index (PI) is plotted against the liquid limit (LL) in Fig. 5. It is observed that the plastic properties of GP lays within the recommended range for materials used for compressed earth blocks (CEB) [Houben 1993; CRTerre_EAG 1998], but that it is just outside the recommended range for adobe bricks [Houben 1993]. However, the plastic properties of GP are very similar to those of the matrix materials used in other studies on adobe bricks, e.g. Vega et al. [Vega 2011] and Araya-Letelier et al. [Araya-Letelier 2018] that used main matrix materials with the following plastic properties: PI of 14%, 12% and a LL of 17%, 17%, respectively.

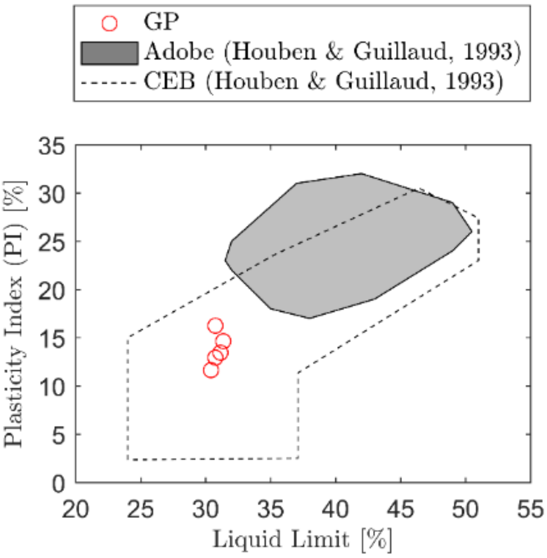

Fig. 5: The plasticity index plotted against the liquid limit for GP. Recommend range for adobe and CEB in accordance with [Houben 1993]

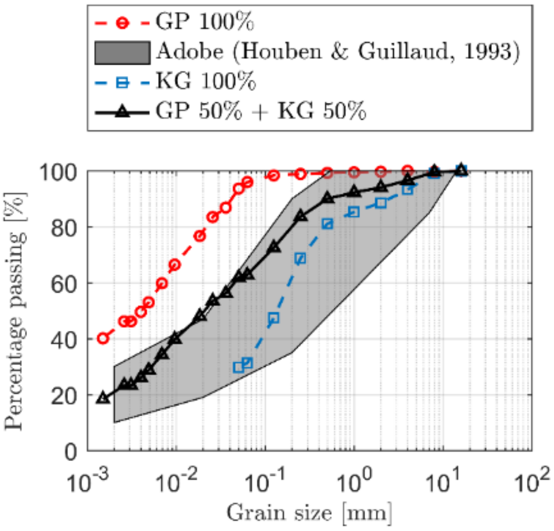

Fig. 6: Grain size distribution for GP, KG and mix of 50% GP and 50% KG. Recommend range in accordance with [Houben 1993]

Grain size distribution for GP and KG

The grain size distribution for GP, KG and a mix of 50% GP and KG, respectively, are shown in Fig. xx. The recommended range for adobe bricks is shown with the grey area [Houben 1993]. The figure shows that the grain size of the pure GP material is too fine grained, whereas the mix of GP and KG lies within the acceptable range.

3.2 Adobe bricks

The performance of the adobe bricks with addition of R-PE fibres were evaluated based on the drying shrinkage behaviour, the three-point bending test and compression tests. All tests were carried out on three replicates.

Drying shrinkage of adobe specimens

The drying shrinkage was measured as the difference between the width and length of wet adobe specimens cast inside the moulds (W = 40 mm, L = 160 mm) and the specimens dried at 30 °C for 48 h. The dry bulk density was calculated in accordance with [CEN-ISO/TS-17892-2 2004] as

$$\rho = \frac{m}{V}$$

, with *m* being the mass and *V* the volume of the dried specimens.

Fig. 7 shows the influence of the addition of R-PE fibres (cleaned in tap water or uncleaned).

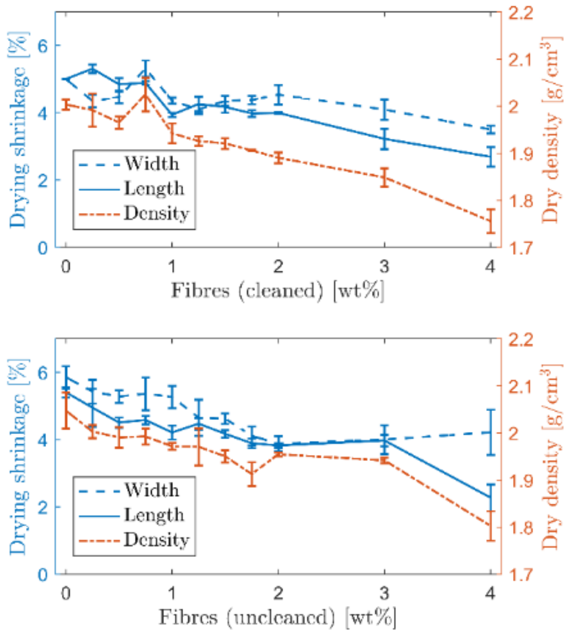

Fig. 7: Drying shrinkage and dry density of adobe prisms with addition of R-PE fibres (cleaned or uncleaned)

First, it is seen that the unreinforced specimens experience/exhibit a large drying shrinkage of 5-6% of the freshly cast specimens. Secondly, it is clearly observed that the addition of R-PE fibres cause a significant decrease in drying shrinkage no matter if the fibres were cleaned in tap water prior to being used or not. This positive influence of fibres on the drying shrinkage in adobe bricks were also observed by [Vega 2011]. Araya-Letelier et al. [Araya-Letelier 2018] studied the influence of pig hair fibres on the formation of restrained drying shrinkage and found that the fibres were significantly reducing the shrinkage cracks when added in 2.0 wt%.

Mechanical performance of adobe specimens

The flexural response of prism-shaped adobe specimens with the addition of cleaned and uncleaned R-PE fibres added in weight fractions of 0.25-4.0wt% are shown in Fig. 8. The first crack strength of ~0.35 MPa was relatively stable for all fibre contents.

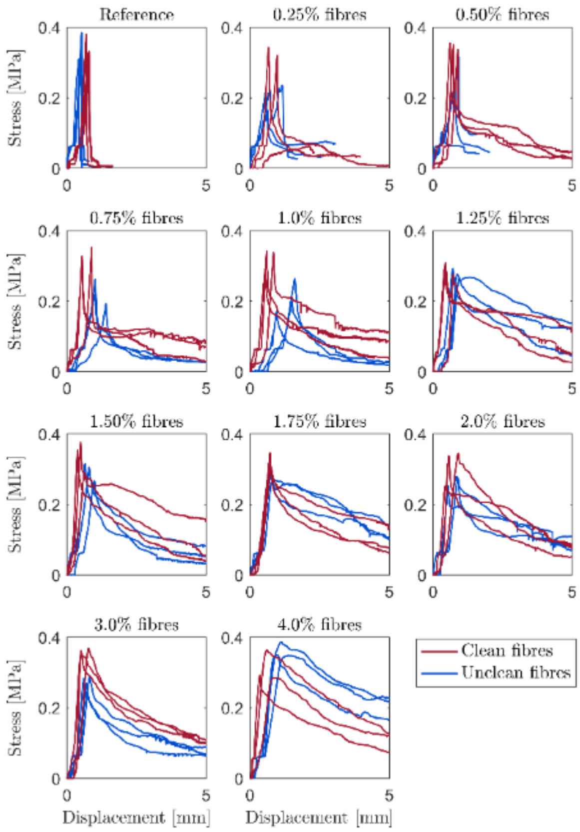

Fig. 8: Stress deflection curves for fibre-reinforced adobe bricks with addition of uncleaned or cleaned R-PE fibres. Fibre additions in wt%

The post-crack performance is significantly improved with the increasing fibre content and there is not observed any major difference in the performance of cleaned and uncleaned fibres. No actual drop in load occurs after the first crack appears, for specimens with fibre contents >2.0wt%. However, even at a fibre content of 4.0wt%, no strain hardening was observed, which was attributed to a relatively poor fibre-to-matrix bonding. PE is a hydrophobic material, which can be one of the reasons for the poor bonding. For future studies it is, therefore, suggested to study possible surface modifications for the R-PE fibres for improving bonding and the stress transfer across the cracks.

The compressive strength was determined on adobe cylinders with no fibres and with a fibre addition of 1.0wt% of cleaned R-PE fibres. The unreinforced specimens obtained a compressive strength of 0.8 MPa, while it was app. 1.0 MPa for the specimens added 1.0wt% of R-PE fibres. Besides the slightly higher compressive strength, the fibre reinforced cylinders showed a much more ductile failure mode, see example in Fig. 9. The results are in the same range as e.g. 0.5-1.2 MPa for those found for adobe bricks collected from existing houses in Portugal [Silveira 2012], but are lower than some other studies on "new" adobe bricks (1.75-3.50 MPa) [Quagliarini 2010]. Please note that other dimensions were used in the mentioned studies, which hinders a direct comparison. However, the material characteristics when exposed compressive stresses should be investigated further on more specimens to evaluate the influence on the addition of fibres.

Fig. 9: Adobe cylinder with addition of 1.0wt% R-PE after compression test

4 RECOMMENDED FUTURE STUDIES

For future studies on the use of GP as main matrix in construction materials, it would be relevant to study other production methods, such as producing CEB instead of adobe bricks. Also, based on the recommendations for the plastic properties by [Houben 1993], the material would be more suitable for CEB than for adobe bricks. By compressing the earth bricks (CEB), it would probably also result in lower drying shrinkage and higher strengths.

Regarding the addition of R-PE fibres obtained from discarded fishing nets, it was observed that the fibre-to-matrix is relatively poor, which could be due to the hydrophobic nature of the PE. For future studies it is therefore recommended to study different types of fibre modifications for improving the bonding. The content of clay minerals in GP could also be a factor related to the poor bonding between the matrix and the R-PE fibres. A high content of clay minerals would probably lead to a better bonding to other materials, because of the high surface area of the clay minerals, thus the content of clay minerals would be relevant to investigate further.

5 CONCLUSION

Adobe specimens were produced from fine-grain rock material (GP) from Greenland, gravel 0-8 mm (KG), water and recycled polyethylene (R-PE) fibres obtained from discarded fishing nets. Prior to the actual production of adobe specimens, the raw materials (GP and KG) were characterized:

- The plastic properties of GP correspond well with those found in other studies on adobe bricks and are within the recommended range for CEB, but slightly outside the range for adobe in accordance with [Houben 1993].
- The grain size distribution of 100% GP was too fine compared to the recommendation for adobe bricks, while the addition of 50% KG was sufficient for getting inside the recommended range of grain sizes.

With respect to the production process of adobe specimens (prisms and cylinders), several iterations were done to obtain a successful process. The following observations were made during these iterations:

- The content of materials with fine grain sizes, such as GP, was significantly influencing the drying shrinkage behaviour (dried at 30 °C for 48 h). Specimens with 100% GP experienced severe cracking induced by drying shrinkage, whereas specimens consisting of 50% GP and 50% KG appeared with only few and fine surface cracks after the accelarated drying process.

- High drying temperatures were also enhancing drying shrinkage, and too low temperatures did not result in sufficient drying of the material within 48 h. The best results were gained by drying the specimens at a temperature of 30 °C for 48 h.
- Fibres were pre-mixed with the dry raw materials to ensure an even fibre distribution.

The drying shrinkage behaviour and the mechanical performance of the adobe bricks showed the following tendencies:

- The drying shrinkage was reduced significantly with increasing fibre content.
- The flexural strength of ~0.4 MPa of the adobe composites was more or less unaffected by the fibre addition.
- The post-crack performance was significantly improved by the addition of fibres. However, the fibres showed a relatively poor fibre-to-matrix bonding. Modification of the fibre surface could be relevant for future studies.
- The compressive strength of cylinders was tested, and the performance of reference specimens (no fibres) (~0.8 MPa) was compared to specimens with 1.0wt% of R-PE fibres (~1.0 MPa). A slightly higher strength and a more ductile failure mode were obtained for the fibre reinforced cylinder.

6 ACKNOWLEDGEMENT

This study was funded through the ERDF Interreg VB Northern Periphery and Arctic (NPA) Programme 2014-2020 (Grant no. 21) and the Toubro foundation (Toubrofonden). The R-PE fibres were kindly provided by Plastix A/S. The authors would like to acknowledge Master student Natacha Makkonen for her help with carrying out the mechanical testing of the adobe specimens.

7 REFERENCES

[Araya-Letelier 2018] Araya-Letelier, G. et al., 2018. Influence of natural fiber dosage and length on adobe mixes damage-mechanical behavior. *Construction and Building Materials*, 174(April), pp.645–655.

[Belmonte 2015] Belmonte, L.J., 2015. *Use of Greenlandic resources for the production of bricks*. Technical University of Denmark.

[Belmonte 2016] Belmonte, L.J. & Bertelsen, I.M.G., 2016. Evaluation of the potential for using greenlandic marine sediments for brick production. In *International RILEM Conference on Materials, Systems and Structures in Civil Engineering*.

[Bergmann 2015] Bergmann, M. et al., 2015. Observations of floating anthropogenic litter in the Barents Sea and Fram Strait, Arctic. *Polar Biology*.

[Bertelsen 2015] Bertelsen, I.M.G. et al., 2015. Properties of bricks produced from Greenlandic marine sediments. In *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions*.

[Bertelsen n.d.] Bertelsen, I.M.G. & Ottosen, L.M., Recycling of waste PE fishing nets as fibre reinforcement in gypsum-based composites. *Submitted*.

[Bertelsen 2019] Bertelsen, I.M.G., Ottosen, L.M. & Fischer, G., 2019. Quantitative analysis of the influence of synthetic fibres on plastic shrinkage cracking using digital image correlation. *Construction and Building Materials*, 199, pp.124–137. Available at: https://doi.org/10.1016/j.conbuildmat.2018.11.268.

[Binici 2005] Binici, H., Aksogan, O. & Shah, T., 2005. Investigation of fibre reinforced mud brick as a building material. *Construction and Building Materials*, 19(4), pp.313–318.

[CEN-ISO/TS-17892-12 2004] CEN-ISO/TS-17892-12, 2004. *Geotechnical investigation and testing – Laboratory testing of soil – Part 12: Determination of Atterberg limits*,

[CEN-ISO/TS-17892-2 2004] CEN-ISO/TS-17892-2, 2004. *Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of density of fine- grained soil*,

[CEN-ISO/TS-17892-3 2004] CEN-ISO/TS-17892-3, 2004. *Geotechnical investigation and testing – Laboratory testing of soil – Part 3 : Determination of particle density*,

[CEN-ISO/TS-17892-4 2004] CEN-ISO/TS-17892-4, 2004. *Geotechnical investigation and testing – Laboratory testing of soil – Part 4: Determination of particle size distribution*,

[CEN-ISO/TS-17892-6 2004] CEN-ISO/TS-17892-6, 2004. *Geotechnical investigation and testing – Laboratory testing of soil – Part 6: Fall cone test*,

[CRTerre_EAG 1998] CRTerre_EAG, 1998. *Compressed Earth Blocks*,

[Houben 1993] Houben, H. & Guillaud, H., 1993. *Earth Construction: A Comprehensive Guide*, Intermediate Technology.

[Pacheco-Torgal 2012] Pacheco-Torgal, F. & Jalali, S., 2012. Earth construction: Lessons from the past for future eco-efficient construction. *Construction and Building Materials*, 29, pp.512–519. Available at: http://dx.doi.org/10.1016/j.conbuildmat.2011.10.054.

[Quagliarini 2010] Quagliarini, E. & Lenci, S., 2010. The influence of natural stabilizers and natural fibres on the mechanical properties of ancient Roman adobe bricks. *Journal of Cultural Heritage*, 11(3), pp.309–314. Available at: http://dx.doi.org/10.1016/j.culher.2009.11.012.

[Silveira 2012] Silveira, D. et al., 2012. Mechanical properties of adobe bricks in ancient constructions. *Construction and Building Materials*, 28(1), pp.36–44. Available at: http://dx.doi.org/10.1016/j.conbuildmat.2011.08.046.

[UNI/EN-196-1 2005] UNI/EN-196-1, 2005. Methods of testing cement – Part 1 : Determination of strength.

[Vega 2011] Vega, P. et al., 2011. Mechanical characterisation of traditional adobes from the north of Spain. *Construction and Building Materials*, 25(7), pp.3020–3023. Available at: http://dx.doi.org/10.1016/j.conbuildmat.2011.02.003.