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PROPERTIES OF BRICKS PRODUCED FROM GREENLANDIC MARINE SEDIMENTS

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ABSTRACT

This study investigated the possibility of a local brick production from fine grained marine sediments (MS) near Sisimiut, Greenland. The assessment is based on the physical and mechanical properties of clay bricks concerning the resistance to the harsh, Arctic weather conditions, together with an identification of a suitable production method. Samples of MS were collected near Sisimiut, Greenland, and tested with respect to the geological properties, which revealed a fine grained, low plasticity silty clay with evenly distributed grain sizes. By a screening of the mineralogy of MS by X-ray diffraction, the major mineral phases were seen to be dominated by quarts and feldspar. Chemical investigations of MS showed low contents of both sulphur and carbon, whereas an unexpectedly high content of chlorine was found. A laboratory-scale study was made on fired brick pellets ($d \sim 20$ mm, $h \sim 3$ mm), and of fired miniature bricks ($54 \times 54 \times 60$ mm^3) of MS from Sisimiut. Brick pellets were prepared in order to determine an optimal composition and production method, based on investigations of the firing temperature and time, forming pressure, initial forming water content, and content of granite waste (CR). Miniature bricks were then prepared according to the optimal conditions and formed at a pressure of 20 MPa, fired at 1020 °C for 3.5 days at the brickwork Wienerberger Tegl in Helsinge, Denmark. The durability properties such as porosity, water absorption, bulk density, linear shrinkage, and compressive strength (only miniature bricks) of both pellets and miniature bricks were investigated and the results were compared with ASTM requirements for building bricks to classify their resistance to damage by freezing. The study of miniature bricks showed that the water absorption was too high after 24 h of submersion in cold water to fulfil the requirements for severe weathering according to ASTM-C62 (2013). It was concluded that the firing temperature needed to be increased in order to obtain a more durable brick-type, suitable for the Arctic climate.

INTRODUCTION

The increase in city population in the bigger towns in Greenland, and a critical housing situation due to many dilapidated buildings, have resulted in long waiting lists on the housing marked (Kalaallit Nunaata Radioa, 2015; Grønlands Statistik, 2015). Since the majority of construction materials used in the Greenlandic construction sector are imported from all over the world, the costs are considerably higher than in e.g. Denmark (Pietras and Jespersen, 2014). Based on this, the idea of using local resources, such as marine sediments in the production of construction material occurred. The possibilities of using the fine grained greenlandic marine sediments for the production of masonry bricks were investigated e.g. by

Belmonte (2014); Olsen and Johansen (2013); Sørensen and Welinder (2003); Jacobsen et al. (2002). The studies used different forming methods, forming water contents, and firing temperatures and -times for the production, why the results are difficult to compare. Belmonte (2014) concluded that it was possible to obtain good quality bricks, but that the quality was highly dependent on the processing of the sediments.
The durability of porous materials is one of the greatest concerns related to using masonry bricks as facing material in the Arctic region, due to frost deterioration, which requires the bricks to have low porosity and water absorption (Kalk- og Teglværksforeningen, 2014). This study has therefore investigated processing parameters (porosity, water absorption, bulk density) in order to determine an optimal production procedure for producing bricks which would be durable in the Arctic climate.

EXPERIMENTAL

Characterization of marine sediments

Fine grained marine sediments (MS) and a fine grained waste material from crushing of granitic rocks (CR) were selected as raw material for a laboratory scale production of masonry bricks. MS were collected from the area around Sisimiut, Greenland, and CR at Betoncentralen in Nuuk, Greenland.
The characterization of MS included determination of geotechnical properties such as plastic-, and liquid limit, and grain size distribution in accordance with DS/CEN-ISO/TS-17892 (2004). The chemical characterization in accordance with Schnell and Ottosen (2008) included an analysis of unwanted elements such as sulphur and total carbon by LECO, calcite grains by volumetric titration with HCl, and salts (Cl^-, SO_4^{2-}) by Ion Chromatography. The loss on ignition (LOI) was calculated as the weight loss between 105 °C and 550 °C fired for 1 h, and as the weight loss between 105 °C and 1000 °C for 2 h. The bulk mineralogical compositions of raw and fired material were characterized together with a characterization of the clay minerals in the $< 2\mu$m raw material fraction by X-ray diffraction with CuK_α radiation (PanAnalytical X'pert Pro).
The thermal behaviour was determined by a thermo-dilatometric analysis (DIL 402C) on samples of 100 % MS (Test 1, 2 and 4) and samples of 80 % MS, 20 % CR (Test 3 and 5). Firing curves with maximum firing temperatures of $1025 - 1050$ °C, a heating-cooling rate of 5 °C/min, which was lowered to 2 °C/min around the quartz inversion at 573 °C in Test 4 and 5 were carried out.

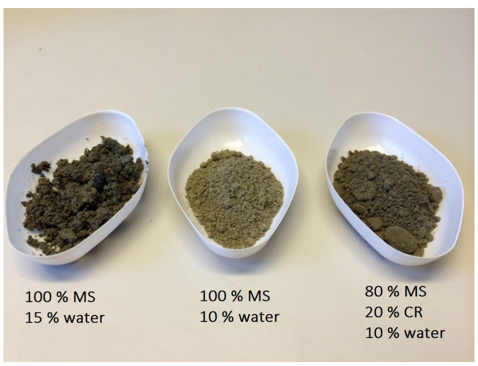
Characterization of fired specimen

Small brick pellets with dimensions in accordance with Torres et al. (2009) ($d = 20$ mm, $m_{\text{dry}} = 2$ g) were produced of MS from Sisimiut (and CR), in order to make preliminary investigations of the influence of different parameters (firing temperature, -time, forming pressure, forming water content, content of CR), and the following working procedures were carried out

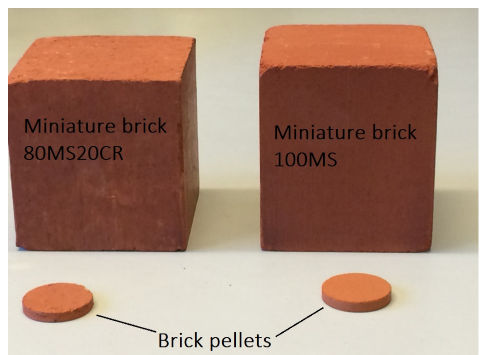
(i) MS was at 105 °C and ground into a powder;
(ii) MS, CR (0 - 20 %) and water (10 - 15 %) were mixed by hand, and left overnight to absorb the moisture;
(iii) Pellets were formed by uniaxial compression at 20-47 MPa with no control of compression rate;
(iv) Dried at 105 °C for 24 h in a non-controlled atmosphere, determination of linear drying shrinkage;
(v) Fired in a muffle furnace with maximum temperatures at $900 - 1050$ °C kept for 1 h, and a heating-cooling rate at ~ 5 °C/min, and determination of linear firing and total shrinkage;
(vi) or fired by following the industrial procedures at Wienerberger Tegl, Helsinge, Denmark, with maximum temperatures at 1020 °C kept for 6 h, and a heating-cooling rate at ~ 20 °C/h for ~ 3.5 days.

Table 1: Overview of pellet production 1-3

Pellet production 1			Pellet production 2			Pellet production 3		
Firing temp.	**Initial w. c.** [%]	**Forming Pressure** [MPa]	**Firing temp.**	**Content of CR** [%]	**Forming Pressure** [MPa]	**Firing temp.**	**Content of CR** [%]	**Firing location** [-]
900	15	47	1025	10	47	1025	0	DTU
950	15	47	1025	15	47	1025	20	DTU
1000	15	47	1025	20	47	$\sim$ 1020	0	WB
1050	15	47	1025	10	20	$\sim$ 1020	20	WB
900	10	47	1025	15	20	-	-	-
950	10	47	1025	20	20	-	-	-
1000	10	47	1050	10	47	-	-	-
1050	10	47	1050	15	47	-	-	-
-	-	-	1050	20	47	-	-	-
Constant for Production 1: CR content 0% Firing location DTU			**Constant for Production 2:** Initial water content 10% Firing location DTU			**Constant for Production 3:** Forming pressure 20MPa, Initial water content 10%		



(a) Raw mixes of MS (and CR) with different water contents.



(b) Fired miniature bricks and brick pellets. Left: 80 % MS, 20 % CR. Right: 100 % MS

Figure 1: Raw mixes and fired pellets and miniature bricks

Pellets with production conditions as stated in Table 1 were produced to evaluate the influence of firing temperature, firing time, forming pressure, forming water content and content of CR. The unfired/fired brick pellets were categorized by determination of linear drying- (LDS), firing- (LFS), and total (LTS) shrinkages measured by a micrometer scale gauge, and calculated as the following equations, where x is the pellet diameter.

$$LTS = \left(\frac{x_{\text{wet}} - x_{\text{fired}}}{x_{\text{wet}}}\right) \cdot 100\% \tag{1}$$

Water absorption, open porosity, and bulk density were determined in accordance with ASTM-C67 (2014) and by following the principles stated by Ti-B-25 (1983), by cold water submersion for 24 h, followed by weighing the pellets under water ($m_{\text{sw.24c}}$) and after wiping away excess water from the surface ($m_{\text{sa.24c}}$). Low water absorption and open porosity, and high bulk density are optimal in order to obtain a durable brick. The pellet properties were used as an indication of the most suitable composition of material and production method and calculated as

$$WA_{24c} = \frac{m_{\text{sa.24c}} - m_{\text{dry}}}{m_{\text{dry}}} \cdot 100\%; \qquad OP_{24c} = \frac{m_{\text{sa.24c}} - m_{\text{dry}}}{m_{\text{dry}} - m_{\text{sw.24c}}} \cdot 100\%; \qquad BD_{24c} = \frac{m_{\text{dry}} \cdot \rho_{\text{w}}}{m_{\text{sa.24c}} - m_{\text{sw.24c}}} \cdot 100\% \tag{2}$$

Based on the linear shrinkage and water absorption testing of brick pellets, miniature bricks with dimensions in accordance with Mezencevova et al. (2012) (54×54×60 mm^3) were prepared by following working procedures (i) and (ii). The miniature bricks were formed by uniaxial compression at 20 MPa (equal to 58.3kN) with a compression rate of 2.00 mm/min from 0 kN to 10 kN and of 1.00 mm/min from 10 kN to F_{max}. Miniature bricks were dried at 105 °C for 72 h, and fired by working procedure (vi) at Wienerberger Tegl. Miniature bricks were classified in weathering grades based on their resistance to freezing by requirement in ASTM-C62 (2013). Determination of the minimum uniaxial compressive strength, maximum water absorption after 24 h cold water submersion followed by 5 h boiling water submersion, and calculation of the saturation coefficient by

$$WA_{5b} = \frac{m_{\text{sa.5b}} - m_{\text{dry}}}{m_{\text{dry}}} \cdot 100\%; \qquad SC_{5\text{b}} = \frac{m_{\text{sw.24c}} - m_{\text{dry}}}{m_{\text{sa.5b}} - m_{\text{dry}}} \tag{3}$$

Open porosity and bulk density were calculated by weighing the saturated miniature bricks under water were calculated by Equation 2 by replacing the 24 h values with the 5 h values. Linear shrinkage was determined as for the brick pellets by Equation 1.

The development of micro structure of dried and fired brick pellets was evaluated by scanning electron microscopy (SEM) of the raw fracture surface.

RESULTS AND DISCUSSION

Characterization of marine sediments

Table 2 shows the geotechnical properties of MS from Sisimiut. In Fig. 2, it can be seen that the grain sizes are evenly distributed and that the sample is dominated by the clay and silt fraction $d < 60\mu$m.

Table 2: Geotechnical properties of MS. Plasticity index $I_{\text{P}} = w_{\text{L}} - w_{\text{P}}$.

Sample	**Natural w.c.** w [%]	**Plastic limit** w_{P} [%]	**Liquid limit** w_{L} [%]	**Plasticity index** I_{P} [%]	**Bulk density** [kg/m^3]	**Particle density** [g/cm^3]
MS	16.1	12.4	17.8	5.4	1554	2.77

An evenly distributed grain size distribution is preferable, since it improves the packing arrangement of the particles, which presumes to lead to a higher degree of contact between the individual grains and thereby a higher degree of sintering (Holmboe, 2001). MS is determined as the soil type "Silty clay loam" based on the grain size distribution, which refers to a moderately fine soil, which is sticky when moist Gribble and McLean (2003). Based on the liquid- and plastic properties, MS is classified as varying from a low plasticity clay (CL) to silt (ML) according to Casagrande (1947).

Table 3 shows the chemical properties of samples of MS. The analysis of TC, S, $CaCO_3$ and calculated TOC (when assumed that the amount of inorganic carbon only originate from $CaCO_3$), showed low values, which will not cause any problems for MS when used as raw material in the production of bricks.

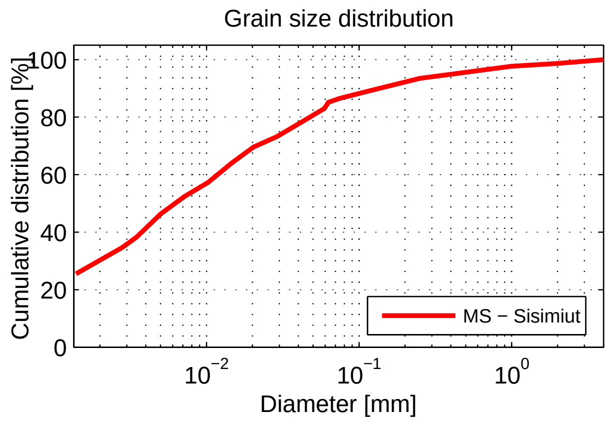


Figure 2: Grain size distribution. Clay fraction $< 2\mu$m, silt fraction $2-60\mu$m, sand fraction $60-2000\mu$m

Table 3: Chemical properties of MS. TC = Total carbon, S = Sulphur, $CaCO_3$ = Calcium carbonate, TOC = Total organic carbon, LOI = Loss on ignition, Cl = Chlorine, SO_4 = Sulphate, SD = Standard deviation.

Sample	**TC** [wt%]	**S** [wt%]	**$CaCO_3$** [wt%]	**TOC** [wt%]	**pH** [-]	**LOI 550** [wt%]	**LOI 1000** [wt%]	**Cl** [mg/kg]	**SD** [-]	**SO_4** [mg/kg]	**SD** [-]
MS	0.16	0.022	0.30	0.12	3.31	1.58	2.17	2361	90	16.3	1.1

Additionally, the low content of $CaCO_3$ is corresponding well with the red colour of the fired product, as a ratio of $CaCO_3/Fe_2O_3 < 3$ gives red bricks (Andersen et al., 1989).
The pH was found to be in the acidic range, which might be due to the low content of carbonates. Low values of LOI after heating to both 550 °C and 1000 °C were observed, which indicate low contents of organic matter, carbonates, and other minerals which decompose at temperatures < 1000 °C.
Salts, such as chlorine and sulphate, were found in the raw MS. A concentration of chlorine > 1000 mg/kg can cause problems such as corrosion of the kiln during firing, and deterioration of the fired brick product by crystallization of the soluble salts inside the pores (Andersen et al., 1989). Belmonte (2014); Olsen and Johansen (2013) observed inconsiderable concentrations of chlorine in samples of MS from Sisimiut. No kind of efflorescence was detected on the surface of the fired product after water submersion and subsequently drying, though further investigations are requested in future studies.

Table 4: Semi-quantitative determination of bulk mineralogy of raw MS by XRD. Mica* = biotite, illite

Sample	**Quartz** [wt %]	**K-feldspar** [wt %]	**Na. Ca- feldspar** [wt %]	**Amphibole** [wt %]	**Pyroxene** [wt %]	**Mica*** [wt %]	**Chlorite** [wt %]
MS	12.0	15.0	42.0	12.0	5.0	12.0	2.0

The semi-quantitative bulk mineralogy of MS, illustrated in Table 4, shows quartz and feldspar as major crystalline phases. The clay mineralogy $d < 2\mu$m of MS from Sisimiut is shown in Fig. 3. The $d = 14.4$ Å peak on the air-dried sample which changed position to $d = 16.3$ Å when glycolated, identifies a content of smectite, which is an expandable clay mineral (Moore and Reynolds, 1997). Chlorite (most likely mixed with a small amount of vermiculite) was identified from the presence and increase of the $d = 14.4$ Å peak and the disappearance of the second order $d = 7.0$ Å reflection on the 550 °C heated sample. Illite (incl. biotite) were identified from the $d = 10.0$ Å peak on the air-dried and glycolated samples. Amphibole was identified from the $d = 8.5$ Å peak. The content of amphibole, together with quartz and feldspar (not shown in the plot), confirmed the presence of non-clay minerals in the clay fraction $< 2\mu$m. The

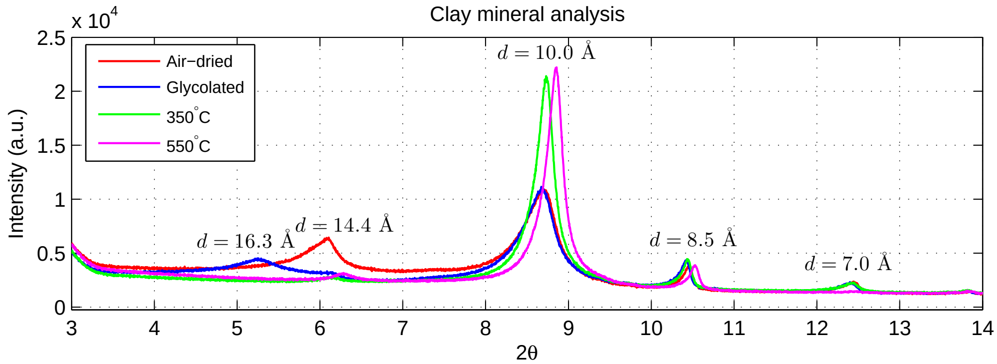
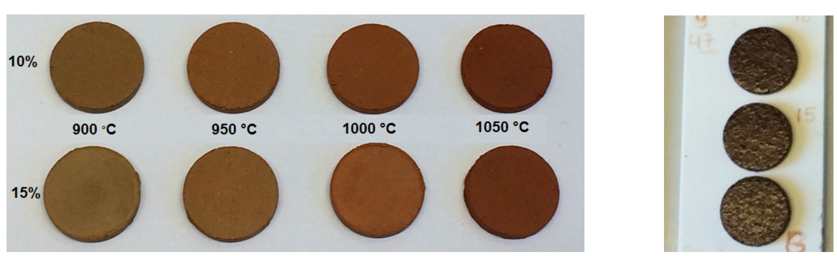


Figure 3: XRD results - clay mineralogy of the clay fraction of MS. Four different samples, Air-dried, solvated in ethylene glycol for 48 h, and heated to 350 °C and 550 °C for 2 h

disagreements in the location of the peaks ($d = 10.0$ Å and $d = 8.5$ Å) between the four samples was considered due to instrument variations.

Characterization of pellets and firing behaviour

Brick pellets ($d \sim 20$ mm, $h \sim 3$ mm) of raw material (MS, CR) with different initial forming water contents were produced, and the appearance of the raw materials was highly influenced by the amount of added water. The material appeared as a loose powder when mixed with 10 % of water, while the mix with 15 % of water gathered in cohesive clods. See Fig. 1a. The difference in the two states was confirmed by the results for the plastic limit at $w_p \sim 12$ %. All types of pellets released some excess water during pressing and appeared greyish when dried. The pellets developed a red colour (due to the formation of haematite, though not confirmed by XRD, and a low content of $CaCO_3$), which became increasingly darker with increasing with firing temperature. See Fig. 4a. Brick pellets of 80% MS, 20% CR fired at 1050°C had produced melt during firing, and the surface appeared glass like with a dark brown colour. See Fig. 4b.



(a) Matrix of pellets made of 100 % MS, fired at different firing temperatures (900°C, 950°C, 1000°C and 1050°C) and with different water contents (10% and 15%)

(b) Pellets of MS with an addition of CR fired at 1050°C

Figure 4: Outcome of Pellet production 1 and a part of production 2

The linear total shrinkages (LTS) of fired brick pellets are illustrated in Fig. 5. The results from Pellet production 1, show that the LTS increased with the firing temperature, but was only considerable for firing temperatures of 1050°C (1.2%) where the densification of the material was initiating. A higher forming water content resulted in slightly higher LTS, which was expected due to a larger linear drying shrinkage (LDS).

The addition of CR in Pellet production 2 lowered the LTS significantly (when fired at 1025°C), which was the primary reason for adding the granite waste (CR). The similar effect of the addition of CR was observed when analysing the firing behaviour by a thermo-dilatometric analysis of mixes with and without an addition of CR, which is illustrated in Fig. 6. Belmonte (2014) observed a strong reduction in linear shrinkage, when CR was added bricks of MS from Illulisat. The samples with CR fired at 1050 °C in Pellet production 2 had shrunken $4-5$ % in diameter and the change in shape was clear due to an initial production of melt (LTS for these pellets, is not shown in Fig. 5).
Two types of pellets were produced in Pellet production 3 (shown in Table 5), one of 100 % MS, and one of 80 % MS and 20 % CR, were fired with a slow firing cycle (20 °C/h in muffle furnace) and with a fast firing cycle (5 °C/min in kiln at Wienerberger Tegl). Almost no difference in LTS was observed for the different two firing cycles, why it was assessed that a fast firing was sufficient for the preliminary investigations of brick pellets. No cracks were observed in any of the pellets.

Table 5: Results of Pellet production 3. TS = Total shrinkage

Content of CR	Firing location	TS mass [%]	TS diameter [%]	Open porosity [%]	Bulk density [kg/m^3]	Water absorption [%]
0	DTU	8.0	0.3	27.5	1916	14.4
20	DTU	9.3	-0.2	25.4	2123	12.0
0	WB	8.7	0.4	27.8	1961	14.1
20	WB	9.6	-0.1	25.4	2043	12.4

The water absorption (WA) after 24 h cold water submersion is depicted in Fig. 5, and shows that WA decreases with increasing firing temperature, forming pressure and addition of CR. A significant decrease was observed for pellets fired at 1050 °C, which was expected due to the noticeable larger linear shrinkage. The behaviour was considered to be related to the higher degree of sintering and thereby densification process produced (for pellets of 100 % MS). In Pellet production 3 shown in Table 5, no noticeable difference was found for pellets fired with a slow firing-cycle or a fast firing-cycle, as it was seen for the total linear shrinkage. Lower WA were observed for pellets with an addition of CR than for pellets of 100 % MS. Similar effects as for the water absorption were observed for the open porosity.
Approximately similar tendencies as for water absorption were observed for the open porosity (OP). The bulk density increased when WA and OP decreased, though a higher level of uncertainties were connected to these measurements due to weighing the units under water.
The optimal composition of production procedures for bricks pellets were evaluated in order to choose the most appropriate ones for a production of miniature bricks, and were assessed to be a (i) firing temperature $>$ 1050 °C for brick pellets of 100 % MS, (ii) a forming water content of 10 %, (iii) a forming pressure of 47 MPa, and (iv) a fast firing-cycle of 5 °C/min, since no difference in durability properties such as WA, OP, BD and LTS were observed. An additional benefit of choosing the fast firing-cycle was the environmental aspect of energy saving for the productions of units for preliminary investigations. The lower forming pressure of 20 MPa was chosen for the production of miniature bricks, as a forming pressure of 47 MPa is probably not economically feasible in a real life brick production. According to Brick Industry Association (2006) the forming pressure of industrial brick production is typically $<$ 10 MPa.

The firing behaviour by a thermo-dilatometric analysis of units (pellet: $h = 8-10$ mm and $d = 5$ mm) with and without an addition of CR are depicted in Figure 6. The following observations were made

- A strong expansion was observed associated with the so-called quarts inversion where the transformation of α-quartz to β-quartz occurs at 573 ° (Andersen et al., 1989).

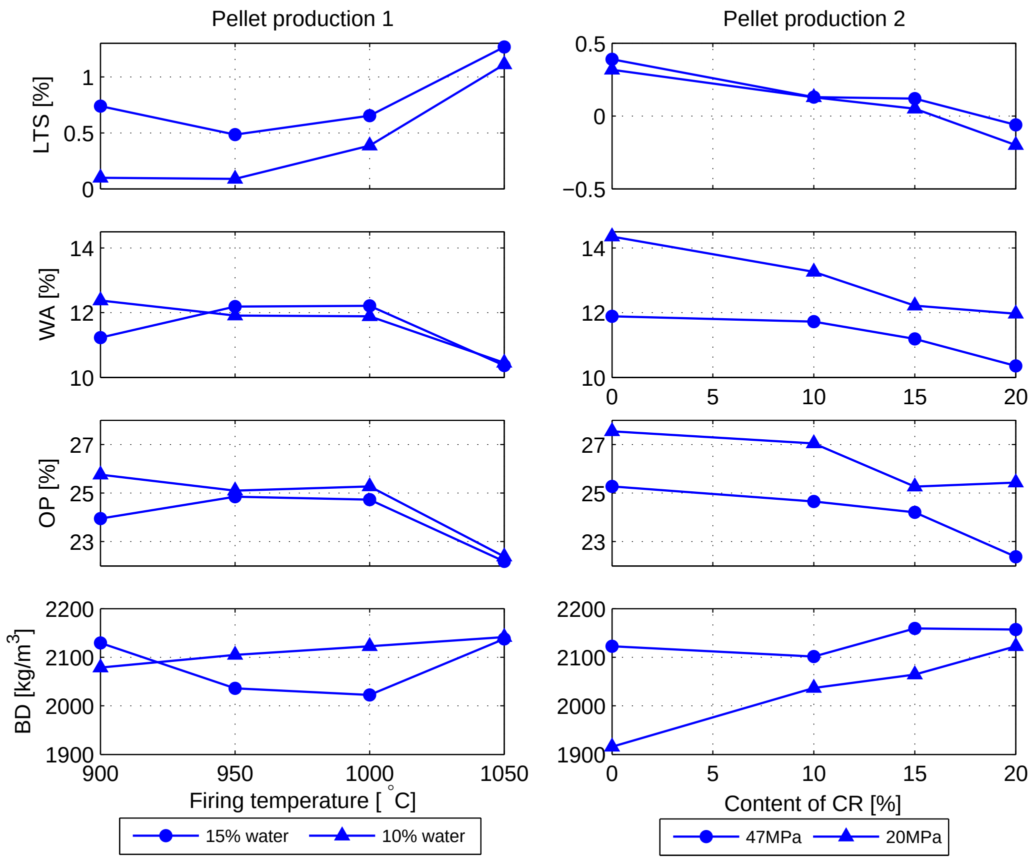


Figure 5: Linear total shrinkage (LTS), water absorption (WA), open porosity (OP) and bulk density (BD) for Pellet production 1-3

- The introduction of CR to the mix resulted in a considerably lower linear shrinkage of the fired units presumably because of a larger content of quartz (Belmonte, 2014).
- The maximum expansion was at 900 °C for all pellets. According to Segadaes et al. (2005); Acchar et al. (2006), a typical firing behaviour of brick clay is a uniform expansion up to 900 °C, whereupon a strong shrinkage occurs due to the dehydroxylation of e.g. clay minerals and micas, which was as well observed.
- A firing temperature of 1050 °C resulted in a much higher linear shrinkage than a firing temperature of 1025 °C (Test 1, 1050 °C: $-5.0 \cdot 10^{-3}$ %. Test 2, 1025 °C: $-1.7 \cdot 10^{-3}$ %).

The micro structures of dried and fired pellets were analysed by SEM images. Pellets of 100 % MS in Fig. 7a and 7b showed a homogeneous fracture surface of the dried as well as of the fired pellet. No clear visual difference was observed between the dried and fired pellets, although the large linear shrinkage and low water absorption indicated that a change happened in the material when fired at 1050°C. On the contrary there was a clear visual difference in the images of pellets of 80 % MS and 20 % CR in the dry and fired condition, Fig. 7c and 7d. The pellets fired at 1050 ° have a micro structure with very few open pores and significant signs of vitrification, which was observed by the appearance of the glassy surface. For pellets of 80 % MS and 20 % CR fired at 1025 °C, an initial sintering was observed though still with a rough micro structure.
The bulk mineralogies of dried or fired samples, are displayed in Fig. 8, which shows various changes between the samples dried at 105 °C, fired at 900 °C and at 1050 °C of 100 % MS, and fired at 1025 °C of 80 % MS and 20 % CR. All samples contain quartz and feldspar as major crystalline phases. Micas

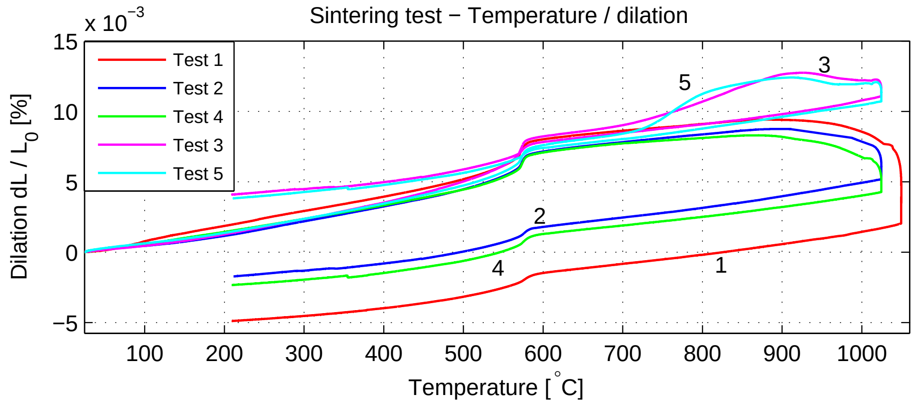
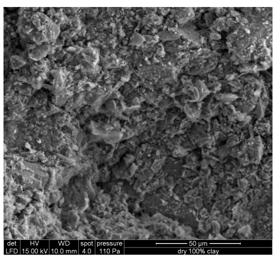
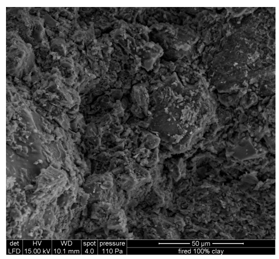


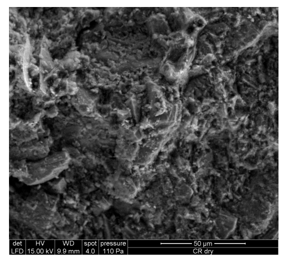
Figure 6: Thermo-dilatometric behaviour. Test 1 = 100MS, 1050 °C; Test 2 = 100MS, 1025 °C; Test 3 = 80MS, 20CR, 1025 °C (heating-cooling rates $\sim$ 5 °/min). Test 4 = 100MS, 1025 °C; Test 5 = 80MS, 20CR, 1025 °C (lowered heating-cooling rates to $\sim$ 2 °C/min between $520-620$ °C).



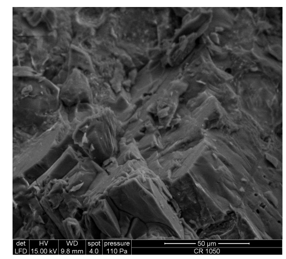
(a) Dry pellet, 100 % MS



(b) Pellet fired at 1050 °C at DTU, 100 % MS



(c) Dry pellet, 80 % MS, 20 % CR



(d) Pellet fired at 1050 °C at DTU, 80% MS, 20% CR

Figure 7: SEM images of fracture surface of pellets of 100 MS and of 80 % MS, 20 % CR. Zoom x800

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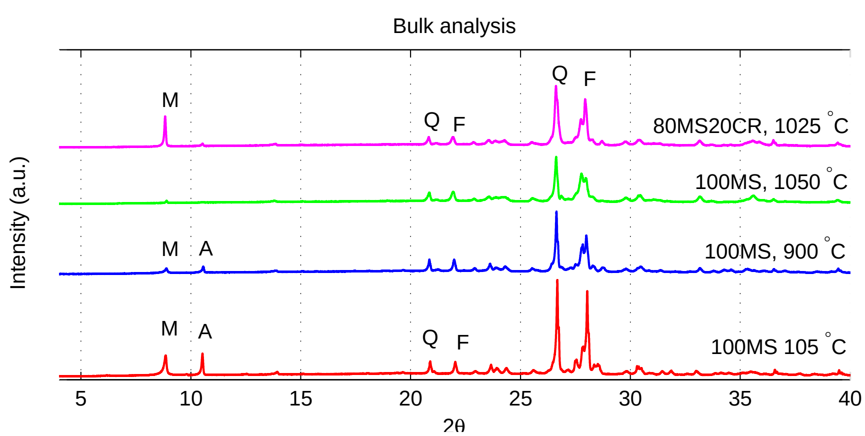

Figure 8: XRD results - bulk mineralogy for pellets heated to 105 °C, 900 °C, 1025 °C, and 1050 °C.
Q = quarts, F = feldspar, M = mica, A = amphibole

(biotite, illite) were identified for all samples fired at temperatures $<$ 1050 °C. The intensity of the peak representing micas at $d = 10$ Å $\sim 2\theta = 8.83$ for 100 % MS decreased with increasing firing temperatures, indicating an almost complete decomposition at 1050 °C. Amphibole was present in the samples of 100 % MS heated to 105 °C / 900 °C. For the MS samples heated to 1050 °C, no amphibole was present, indicating decomposition below this temperature. The change in the feldspar peak positions at higher temperatures was probably due to a phase change from low-temperature feldspar to high-temperature feldspar.

Characterization of miniature bricks

Based on the results from the preliminary investigations of brick pellets, two types of miniature bricks ($54\times54\times60$ mm^3) were produced.

Table 6: LTS, WA, OP and BD of bricks after 24 h of submersion in cold water, after 5 h of boiling (ASTM-C67, 2014). Results from water absorption test of brick pellets produced by similar procedures

	Content of CR	**Linear total shrinkage**	**Water absorption 24c**	**Water absorption 5b**	**Open porosity 24c**	**Open porosity 5b**	**Bulk density 24c**	**Bulk density 5b**
	[%]	[%]	[%]	[%]	[%]	[%]	[kg/m^3]	[kg/m^3]
Brick 100MS	0	0.68	12.7	14.1	25.2	28.0	1991	1992
Brick 80MS20CR	20	-0.04	10.8	11.8	22.6	24.6	2087	2091
Pellet 100MS	0	0.41	14.1	-	27.8	-	1961	-
Pellet 80MS20CR	20	-0.11	12.4	-	25.4	-	2043	-

The linear total shrinkage (LTS), water absorption (WA), open porosity (OP) and bulk density (BD) of miniature bricks and brick pellets (produced by similar methods) are shown in Table 6. It can be seen, that the properties for miniature bricks and brick pellets are very similar, why it was concluded that the preliminary investigations of brick pellets are useful in order to predict the properties of bricks of larger dimensions. As for the brick pellets, the miniature bricks containing CR had obtained the lowest linear total shrinkage, water absorption and open porosity, and the largest bulk density.

Table 7: Physical properties of miniature bricks and requirement in (ASTM-C62, 2013). N.L. = no limit

Type of brick	**Content of CR**	**Minimum Compressive strength**		**Maximum Water absorption, 5b**		**Maximum Saturation coefficient**	
		Average	**Individual**	**Average**	**Individual**	**Average**	**Individual**
	[%]	[MPa]	[MPa]	[%]	[%]	[-]	[-]
100MS	0	46.3	43.3	14.1	14.2	0.90	0.91
80MS20CR	20	40.6	36.0	11.8	11.9	0.92	0.93
ASTM: Grade SW	-	20.7	17.2	17.0	20.0	0.78	0.80
ASTM: Grade MW	-	17.2	15.2	22.0	25.0	0.88	0.90
ASTM: Grade NW	-	10.3	8.6	N.L.	N.L.	N.L.	N.L.

Based on the results of compressive strength, water absorption after 5 h of boiling, and the saturation coefficient, the miniature bricks were classified with respect to the freeze-thaw resistance by the requirements in ASTM-C62 (2013), and are shown in Table 7. Both types of miniature bricks, 100MS and 80MS20CR, met the ASTM-C62 (2013) requirements for the NW grade (Negligible weathering), however the values of the minimum compressive strength, and the maximum water absorption after boiling for 5 h met the requirements for the SW grade (Severe weathering). The saturation coefficient (SC) was high due to the high WA after 24 h cold water submersion for both brick types. According to ASTM-C62 (2013) the WA for cold water submersion for 24 h must not exceed 8 %.

CONCLUSION

The possibility of making bricks using fine grained marine sediments (MS) from Sisimiut, Greenland, as primary material, was investigated in this study. Fired units (pellets and miniature bricks) of MS were produced and their durability properties and firing behaviour characterized. Additionally, investigations of the geotechnical, chemical and mineralogical properties of the raw material were carried out.
From the experimental work performed in this study, the following conclusions are derived:

- The geotechnical investigations revealed a fine grained silty clay loam of low plasticity, with an even grain size distribution. MS was found to have a low loss on ignition, low content of sulphur, carbon, calcium carbonate and sulphate, but a high concentration of chlorine, which might be problematic when used in a production of masonry bricks. No salt efflorescence was observed on the fired units after submersion in water. The mineralogical composition of the material showed a dominance of feldspar and quartz, and a low content of clay minerals, which correlates well with the low plasticity.
- From the preliminary production of fired brick pellets it was found that increasing firing temperature, forming pressure, and addition of granite waste improved the quality and durability of the fired pellets. On the other hand, an increase in firing time did not lead to any significant improvements of the properties, shown by the results from Pellet production 3.
- Firing behaviour of samples of MS confirmed that an addition of granite waste (CR) lowered the linear shrinkage substantially and that the firing temperature > 1050 °C increased the shrinkage.
- The pellets and miniature bricks, when fired, obtained a red colour, which was magnified with increasing firing temperature and corresponds with the low content of calcium carbonate. No surface cracking was observed, which was connected with the low content of initial forming water and the dry-pressing forming method.
- Physical and mechanical properties of miniature bricks were obtained by following ASTM-C62 (2013) The compressive strength (40 – 46 MPa) and water absorption after boiling for 5 h (12 – 14 %), met the requirements for the SW grade. However, the saturation coefficient (0.90 – 0.92 %), and the water absorption after submersion in cold water for 24 h (11 – 13 %), were too high and the bricks therefore only met the requirements for the NW grade (Negligible weathering) by ASTM-C62 (2013). The recommended improvement would be to increase the firing temperature in order to meet the SW grade, which would be suited for the Arctic climate.

Based on the obtained results, it is demonstrated that fine grained marine sediments as the primary material in the production of fired bricks is promising, even though all the requirements for the SW grade according to ASTM-C62 (2013) were not fulfilled.

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