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*Article*

# Effect of curd whey on the shrinkage and water absorption of fired clay building ceramics

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**Abstract.** This study examines the effect of curd whey, introduced as part of the mixing liquid, on the shrinkage and water absorption of fired clay building ceramics. The ceramic body was prepared from a 50:50 mixture of low-firing clays from the Ivanovo and 24th Party Congress deposits (Akmola Region, Kazakhstan). Curd whey replaced 15% and 20% of the mixing liquid by volume, with a whey-free composition used as the reference. Specimens were shaped by plastic forming and fired at 850, 900, 950, 1000, 1050, and 1100 °C. Firing shrinkage, total shrinkage, and water absorption were determined on five specimens for each combination of composition and firing temperature; no values were recorded for seven combinations, which are identified in the text. The addition of 15% whey reduced firing shrinkage at every firing temperature at which it was measured: at 1050 °C, firing shrinkage was 0.9 ± 0.08% for the composition containing 15% whey against 1.6 ± 0.08% for the reference. Water absorption of the 15% whey composition remained higher than that of the reference at every firing temperature at which both were tested, reaching 7.9 ± 0.25% against 5.2 ± 0.20% at 1100 °C, whereas the 20% whey composition exceeded the reference at 950–1050 °C but not at 850 and 900 °C. These trends are consistent with the formation of additional porosity through decomposition of the organic constituents of the whey during firing; porosity, density, and microstructure were not measured directly in the present work, so this interpretation is presented as a proposed explanation. The results show that liquid curd whey can be used as part of the forming liquid to modify the shrinkage behavior of clay ceramics and provide a basis for the mechanical and microstructural characterization needed to establish practical performance.
**Keywords:** building ceramics, curd whey, dairy by-product, forming liquid, firing shrinkage, water absorption, plastic forming, waste valorization.

## 1. Introduction

One of the key areas of modern materials science and a priority area of modern construction materials science is the development of resource-efficient technologies that utilize industrial and organic waste [1]. The growing volume of waste generated by the food industry, as well as the need to reduce human impact on the environment, underscores the importance of incorporating secondary resources into the production of building materials. Silva et al. [2] note the potential of organic and industrial waste in porous ceramic technology as one route to resource conservation. Kirchherr et al. [3] treat the return of waste into production cycles as a defining principle of the circular economy, and Geissdoerfer et al. [4] argue that the reuse of secondary resources supports more sustainable and environmentally oriented technological systems.

Among food industry wastes, significant volumes are generated in dairy production, where whey is one of the most common byproducts. Prazeres et al. [5] note that whey is characterized by a high content of organic matter, proteins, and lactose; consequently, its discharge without prior treatment can cause significant pollution of water bodies. Smithers [6] indicates that whey has high potential for reuse due to its content of organic and mineral components; however, a substantial proportion of the whey generated worldwide is still not valorized and is discharged or applied to land rather than recovered [7].

In recent years, research on the use of organic waste in building ceramics technology has been actively developing [8], [9], [10], [11]. Demir [12] investigated the effect of organic residues on the technological properties of clay bricks and found that the combustion of organic components during firing contributes to the formation of additional porosity and a reduction in the material's density. At the same time, the author notes that an increase in the content of organic additives can lead to a deterioration in the strength characteristics of the products [13], [14], [15], [16].

Bories et al. [17] investigated the potential use of agricultural biomass in the production of ceramic materials. They found that incorporating organic waste promotes the formation of a more porous structure and reduces the thermal conductivity of the ceramic body. However, the effect of such additives on shrinkage and structural formation processes has been studied only to a limited extent.

Adazabra et al. [18] investigated the incorporation of spent shea waste into construction clay bricks and showed that increasing the content of the organic component raises open porosity and water absorption. The authors note the need to identify an appropriate concentration of organic additive to retain the required properties of the fired product.

In a review, Monteiro and Vieira [19] highlight the potential of using organic components as pore-forming additives. They also emphasize that the mechanisms by which various types of organic waste influence sintering and structural formation processes remain poorly understood.

Sutcu and Akkurt found that using organic waste from the paper industry enables the production of ceramic materials with reduced thermal conductivity due to the formation of a highly developed porous structure. However, an excessive amount of organic additive was accompanied by an increase in open porosity and a deterioration in performance characteristics [20].

Eliche-Quesada et al. [21] demonstrated the potential for using wood and organo-mineral waste in the production of building ceramics. The authors note that the combustion of organic components significantly affects densification and structural formation in the material during heat treatment.

Studies [22] and [23] note that the use of organic and industrial waste not only reduces the consumption of natural raw materials but also allows for the regulation of the physical and mechanical properties of building ceramics by modifying the pore formation and sintering processes [24], [25].

The literature is therefore dominated by solid organic pore-forming additives (agricultural residues, sawdust, and paper or industrial waste) introduced into the clay in dry form. Dairy-industry residues have been examined mainly in the solid state: Simón et al. [26] used sludge from the treatment of dairy effluent as a partial clay substitute in fired bricks and characterized its chemical and mineralogical composition together with the porosity and mechanical properties of the resulting product. Liquid curd whey introduced as part of the mixing liquid, rather than as a solid substitute for clay, has received considerably less attention, and its effect on shrinkage and water absorption as a function of firing temperature has not been reported.

This study aims to quantify the effect of curd whey, introduced as part of the mixing liquid, on the firing shrinkage, total shrinkage, and water absorption of clay building ceramics fired at 850–1100 °C.

The novelty of this study lies in the use of liquid curd whey as part of the forming liquid, rather than as a dried or solid additive, and in quantifying its effect on the shrinkage and water absorption of clay ceramics over the range 850–1100 °C. The practical relevance of the work lies in the possibility of replacing part of the mixing water with an unprocessed dairy by-product; establishing whether the resulting material meets the requirements for building products will require the mechanical and durability testing outlined in the Limitations section.

## 2. Methods

The primary raw material used to produce the ceramic samples was a 50:50 mixture of low-firing clays from the Ivanovo deposit (Akmola Region, Kazakhstan) and the 24$^{th}$ Party Congress of the CPSU deposit (Akmola Region, Kazakhstan).

The chemical composition of both clays was determined by X-ray fluorescence spectrometry (Bruker S8 TIGER, Bruker AXS GmbH, Karlsruhe, Germany), and the mineralogical composition by X-ray diffraction (Bruker D8 ADVANCE, Bruker AXS GmbH, Karlsruhe, Germany). Particle-size distribution was determined by laser diffraction (Mastersizer 3000+, Malvern Panalytical, Malvern, United Kingdom) according to ISO 13320:2020 [27], plasticity was characterized by the Atterberg limits using a KBV Vasilyev balance cone (DorLab LLC, Moscow, Russia) according to GOST 5180-2015 [28], and loss on ignition was determined at 1000 °C in the muffle furnace SNOL 13/1100 LHM01 (SnolTherm, UAB, Utena, Lithuania). The results are given in Table 1.

Table 1 – Characteristics of the clay raw materials

| Characteristic | Ivanovo clay | 24$^{th}$ Party Congress clay | Method/standard |
|---|---|---|---|
| $SiO_2$, % | 61.2 | 56.8 | XRF, Bruker S8 TIGER |
| $Al_2O_3$, % | 17.4 | 15.9 | |
| $Fe_2O_3$, % | 6.1 | 6.7 | |
| CaO, % | 3.6 | 7.4 | |
| MgO, % | 2.0 | 2.6 | |
| $K_2O + Na_2O$, % | 3.5 | 3.2 | |
| Loss on ignition, % | 5.3 | 6.3 | Gravimetric method, 1000 °C |
| Main mineral phases | Quartz, illite, kaolinite, feldspar; minor calcite and hematite | Quartz, illite, kaolinite, calcite, feldspar; minor dolomite and hematite | XRD, Bruker D8 ADVANCE |
| Fraction < 5 µm, % | 38.2 | 31.5 | Laser diffraction, ISO 13320:2020 [27] |
| Fraction 5–50 µm, % | 47.6 | 49.8 | |
| Fraction > 50 µm, % | 14.2 | 18.7 | |
| Plasticity index | 18.6 | 15.2 | GOST 5180-2015 [28] |
| Natural moisture, % | 20.2 | 18.7 | |

Before use, the clay raw material underwent preliminary processing, which included drying to an air-dry state, grinding in an SM 100 cutting mill (RETSCH GmbH, Haan, Germany), and screening through a 1.0 mm laboratory test sieve (RETSCH GmbH, Haan, Germany) to obtain a uniform fraction.

Curd whey, a by-product of cottage cheese manufacture, was used as the organic component of the mixing liquid. The whey was supplied by Gormolzavod LLP (Kokshetau, Kazakhstan); fresh batches were collected regularly throughout the experimental program and stored at 2–4 °C for no longer than 24 h before use. Density was determined by pycnometry using a PZh-2 pycnometer with a nominal capacity of 50 mL (JSC Khimlaborpribor, Klin, Moscow Region, Russia) according to GOST 3625-84 [29], fat content according to GOST 5867-90 [30], protein content according to GOST 25179-2014 [31], lactose (sugar) content according to GOST 3628-78 [32], and mineral elements according to GOST ISO 8070/IDF 119-2014 [33] by AA-7000 atomic absorption spectrometer (Shimadzu Corporation, Kyoto, Japan). Arsenic, lead, and cadmium were determined by inductively coupled plasma mass spectrometry according to GOST 34141-2017 [34] using a 7900 ICP-MS (Agilent Technologies, Tokyo, Japan), while mercury was determined according to GOST 26927-86 [35] using a RA-915M mercury analyzer (Lumex Instruments, Saint Petersburg, Russia). Total solids content was determined according to GOST 3626-73 [36] by the gravimetric method (drying to constant weight) using a UN55 laboratory drying oven (Memmert GmbH + Co. KG, Schwabach, Germany). The pH value was determined according to GOST 32892-2014 [37] by the potentiometric method using a SevenCompact S220 pH meter (Mettler Toledo, Greifensee, Switzerland). The composition and properties of the whey are summarized in Table 2; the whey is acidic (pH 4.62) and contains 6.15% lactose, 2.02% protein, and 0.66% fat, which together constitute the organic fraction expected to decompose during firing. Arsenic, lead, cadmium, and mercury were not detected.

Table 2 – Summary of the composition and properties of the whey sample under study

| Category | Indicator | Unit of measurement | Method/standard | Test result |
|---|---|---|---|---|
| Physical and chemical | Density | g/cm$^3$ | GOST 3625-84 [29] | 1.046 |
| | pH | - | GOST 32892-2014 [37] | 4.62 |
| | Fat content | % | GOST 5867-90 [30] | 0.66 |
| | Protein content | % | GOST 25179-2014 [31] | 2.02 |
| | Lactose (sugar) content | % | GOST 3628-78 [32] | 6.15 |
| Mineral composition | Potassium (K) | mg/kg | GOST ISO 8070/IDF 119-2014 [33] | 1050.6 |
| | Sodium (Na) | mg/kg | | 248.3 |
| | Magnesium (Mg) | mg/kg | | 75.54 |
| | Calcium (Ca) | mg/kg | | ND |
| Toxic elements | Arsenic (As) | mg/kg | GOST 34141-2017 [34] | ND |
| | Lead (Pb) | mg/kg | | ND |
| | Cadmium (Cd) | mg/kg | | ND |
| | Mercury (Hg) | mg/kg | GOST 26927-86 [35] | ND |

Note: ND – not detected; calcium was reported as 0.0 mg/kg in the laboratory analytical report, and detection limits were not stated; a calcium content below detection is unexpected for curd whey, which normally retains soluble calcium; the value is reported as received from the laboratory.

The process of preparing and mixing the plastic ceramic body with the addition of whey is shown in Figure 1.

a) Preparation and mixing b) Addition of whey

Figure 1 – Preparation and mixing of the plastic ceramic body

Each batch was prepared from 7.0 kg of clay (3.5 kg of each clay in the air-dry state) and 1.5 L of mixing liquid, giving a liquid-to-solid ratio of 0.214 L/kg. In the modified compositions, curd whey replaced 15% and 20% of the mixing liquid by volume (v/v); the balance was tap water. The exact volumes are given in Table 3.

Table 3 – Experimental compositions and mixing liquid

| Composition | Clay, kg | Water, mL | Curd whey, mL | Whey, % v/v of liquid | Total liquid, mL | Liquid/solid, L/kg |
|---|---|---|---|---|---|---|
| Reference | 7.0 | 1500 | 0 | 0 | 1500 | 0.214 |
| 1 | 7.0 | 1275 | 225 | 15 | 1500 | 0.214 |
| 2 | 7.0 | 1200 | 300 | 20 | 1500 | 0.214 |

The specimens were shaped by plastic forming using a laboratory extruder (NVS-07, Nidec-Shimpo Corp., Kyoto, Japan) with a 15 × 20 mm rectangular die. The body was passed through the extruder 5 times until a homogeneous column free of cracks and laminations was obtained. After that, samples in the form of beams measuring 100×20×15 mm were formed. The experimental samples after forming are shown in Figure 2.

Figure 2 – Prepared samples of building ceramics before drying and firing

After molding, the samples were pre-dried under laboratory conditions until they reached a constant mass, thereby reducing the likelihood of defects forming during subsequent firing.

The samples were dried by gradually increasing the temperature in several stages: 30, 45, and 60 °C. The drying time in the tunnel dryer (SEC-TBP-500, SOLINCER S.L., Vilanova del Camí, Spain) was approximately two days. Afterwards, the samples were further dried in a laboratory oven (UN55, Memmert GmbH + Co. KG, Schwabach, Germany) at 105 °C for at least 12 hours until a constant mass was reached.

Firing was carried out in a laboratory muffle furnace SNOL 13/1100 LHM01 (SnolTherm UAB, Utena, Lithuania) in a static air atmosphere at 850, 900, 950, 1000, 1050, and 1100 °C. Specimens were placed on a metal support in a single layer with a spacing of 10 mm, 15 specimens per firing. The schedule was: heating to 200 °C at 2 °C/min with a dwell of 30 min; heating from 200 to 600 °C at 2 °C/min with a dwell of 60 min at 600 °C; heating to the target temperature at 2 °C/min; a dwell of 60 min at the target temperature; and free cooling in the closed furnace to below 100 °C at an average rate of 1 °C/min. The total cycle therefore ranged from 21.9 h for the 850 °C regime to 28.2 h for the 1100 °C regime, the difference arising entirely from the length of the heating and cooling ramps.

To assess the effect of whey on the properties of the ceramic body, the drying shrinkage, firing shrinkage, total shrinkage, and water absorption of the samples were determined. The methods for determining the studied parameters are presented in Table 4.

Table 4 – Methods for determining the properties of ceramic samples in accordance with GOST 530-2012 [38] and GOST 7025-91 [39]

| № | Test Parameter | Standard / clause | Procedure | Precision |
|---|---|---|---|---|
| 1 | Drying Shrinkage | GOST 530-2012 [38], clauses 7.3.1–7.3.2 (linear-dimension measurement); shrinkage calculated according to the experimental procedure | Linear dimensions measured on the same marked gauge length before and after drying to constant mass | ±0.02 mm, digital caliper (Mitutoyo ABSOLUTE Digimatic 500-196-30, Mitutoyo, Japan; resolution 0.01 mm) |
| 2 | Firing Shrinkage | | Linear dimensions measured before and after firing | |
| 3 | Total Shrinkage | | Green length vs fired length on the same gauge marks | |

| | | | | |
|---|---|---|---|---|
| 4 | Water Absorption | GOST 7025-91 [39], clauses 2.2, 2.3.1–2.3.3 and 2.4.1 | Saturation in water at 20±5 °C for 48 h, surface-dried, weighed; dried to constant mass at 105 °C | ± 0.001 g, Laboratory Balance (Pioneer PX323, OHAUS Corporation, Parsippany, NJ, USA) |

Note: Both standards [38], [39] specify tests on full-size bricks. In this work, they were applied to laboratory beams of 100 × 20 × 15 mm; the saturation procedure, drying regime and calculation formulae were followed without change, while the specimen dimensions and the number of specimens per determination were adapted to laboratory scale. Results obtained on beams are therefore comparable between the compositions studied but are not directly transferable to full-size products.

The shrinkage characteristics were determined by measuring the linear dimensions of the specimens before and after each heat-treatment stage. Water absorption was determined by the gravimetric method after the specimens were saturated with water.

Drying shrinkage $S_d$, firing shrinkage $S_f$, total shrinkage $S_t$, and water absorption W were calculated as:

$$S_d = \frac{(L_g - L_d)}{L_g} \times 100, \quad (1)$$

$$S_f = \frac{(L_d - L_f)}{L_d} \times 100, \quad (2)$$

$$S_t = \frac{(L_g - L_f)}{L_g} \times 100, \quad (3)$$

$$W = \frac{(m_s - m_d)}{m_d} \times 100, \quad (4)$$

where: $L_g$, $L_d$ and $L_f$ are the lengths between the same gauge marks after forming, after drying and after firing, and $m_d$ and $m_s$ are the dry and water-saturated masses of the fired specimen.

Five independent specimens were prepared and tested for each combination of composition and firing temperature, giving 3 compositions × 6 firing temperatures × 5 specimens = 90 specimens in total. No specimen was reused between temperature regimes or between successive determinations. Directly measured values were not obtained for the following combinations: firing shrinkage of the 15% whey composition at 950 and 1000 °C and of the 20% whey composition at 900, 1000 and 1100 °C; and water absorption of the 15% whey composition at 850 °C and of the 20% whey composition at 1100 °C. The values reported are means of five specimens, with standard deviations given where they were recorded. The individual specimen measurements were not retained; drying shrinkage, which was determined as an intermediate quantity, is therefore not reported separately. Because the individual measurements are not available, no formal statistical test could be performed, and differences between compositions are described in terms of mean values only.

To analyze the effect of the organic additive, a comparative study was conducted to examine changes in shrinkage characteristics and water absorption as functions of firing temperature and whey content in the mixing liquid.

The physical properties of the ceramic specimens (linear shrinkage and water absorption) were determined in accordance with current regulatory documents. Mechanical properties were not determined in this study. Water absorption was determined in accordance with GOST 7025-91 [39]. Linear shrinkage was determined in accordance with the requirements of GOST 530-2012 [38].

## 3. Results and Discussion

### *3.1 The effect of whey on shrinkage processes*

The addition of whey altered the shrinkage behavior of the ceramic body during firing. The reference composition exhibits a gradual increase in both firing and total shrinkage as firing temperature increases. This pattern is due to intensified sintering and the densification of the ceramic material's structure during high-temperature processing. The maximum firing shrinkage of the reference composition, 2.8 ± 0.12%, and the maximum total shrinkage, 10.3 ± 0.15%, were both recorded at 1100 °C. The dependence of firing shrinkage on firing temperature is shown in Figure 3.

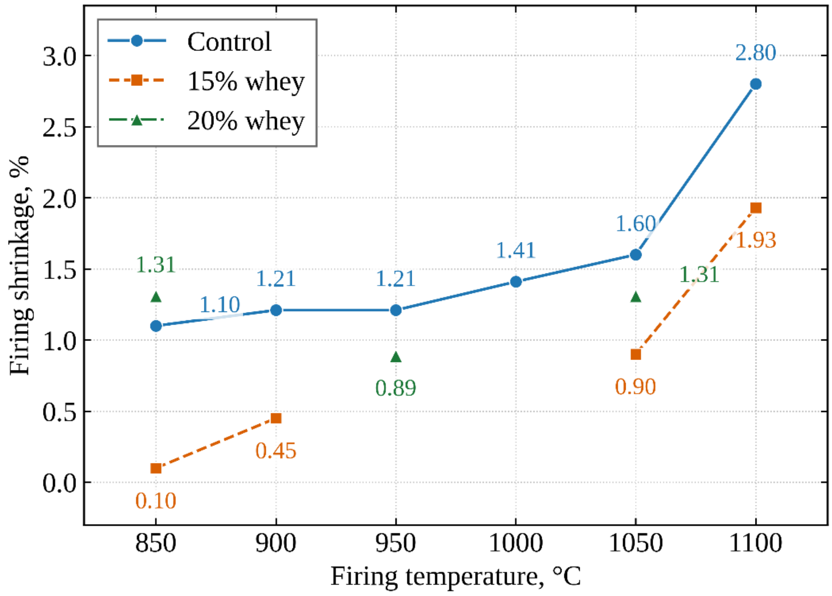


Figure 3 – The relationship between firing shrinkage and firing temperature (data are means of five specimens; combinations for which no measured value was obtained (Section 2) are not shown)

The addition of 15% whey altered the nature of the shrinkage processes. At every temperature at which it was measured (850, 900, 1050 and 1100 °C), firing shrinkage was lower than that of the reference composition. Thus, at 1050 °C, firing shrinkage was 0.9 ± 0.08%, whereas for the reference it was 1.6 ± 0.08%. A plausible explanation for the reduced shrinkage is that decomposition of the organic constituents of the whey generates additional porosity, which partially offsets the densification occurring during sintering. Since pore size and pore-size distribution were not measured in this work, this remains an interpretation of the shrinkage data rather than a directly demonstrated mechanism.

The results obtained are consistent with Demir [12], who established that the introduction of organic additives helps reduce shrinkage deformations by creating additional porosity during firing. Similar behavior was reported by Bories et al. [17], who showed that the combustion of organic biomass helps partially compensate for internal stresses during the heat treatment of ceramic materials. The change in total shrinkage of the studied compositions is shown in Figure 4.

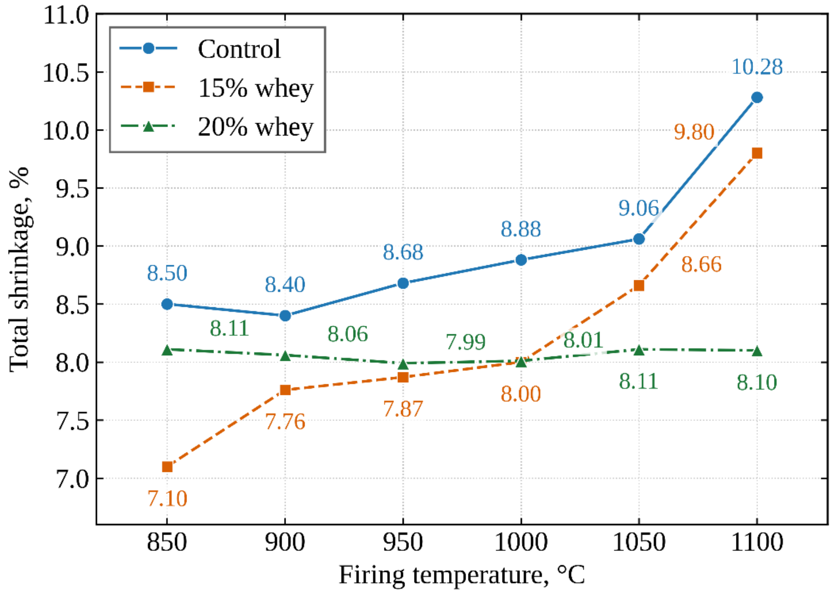


Figure 4 – The relationship between total shrinkage and firing temperature

When the firing temperature is increased to 1100 °C, an intensification of liquid-phase sintering processes is observed, accompanied by structural densification and increased shrinkage deformations. Even at this temperature, however, the composition containing 15% whey showed lower firing shrinkage than the reference. At a whey content of 20%, firing shrinkage was less regular with respect to temperature than for the other two compositions, and total shrinkage remained almost constant at 8.0–8.1% across the whole range. Water absorption of this composition was the highest of the three at 950, 1000, and 1050 °C (Section 3.2). Taken together, these observations are consistent with more intense gas evolution during decomposition of the organic constituents, although neither porosity nor bulk density was measured, and this explanation is not directly verified here.

Thus, the study's results show that introducing curd whey helps regulate shrinkage in the ceramic body. Of the two whey contents examined, 15% gave the largest and most consistent reduction in firing shrinkage relative to the reference. Because only two non-zero whey contents were tested, these data do not permit the identification of an optimum, and a wider concentration range would be needed to locate one.

*3.2. The effect of firing temperature on water absorption*

The addition of whey changed the water absorption of the fired specimens across the whole temperature range studied (Figure 5). In the reference composition, water absorption decreases steadily as heat treatment temperature increases. As the firing temperature increased from 850 to 1100 °C, water absorption of the reference composition decreased from 13.6 ± 0.30% to 5.2 ± 0.20%. This pattern is due to the development of sintering processes, accompanied by densification of the material structure and a reduction in the volume of open pores. At temperatures above 1000 °C, liquid-phase sintering intensifies, and capillary porosity partially closes as the ceramic body densifies. Similar behavior was reported by Sutcu and Akkurt [20], who showed that increasing firing temperature reduces the water absorption of porous ceramics by activating structural densification processes.

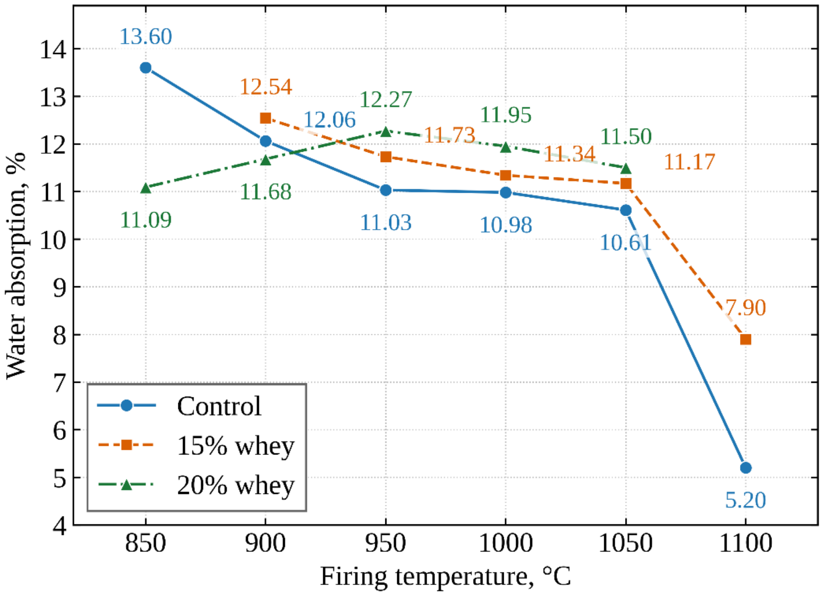


Figure 5 – The relationship between water absorption and firing temperature

The introduction of 15% whey altered the nature of the water absorption behavior. At every firing temperature at which the composition was tested (900–1100 °C), water absorption values remained higher than those of the reference composition. Thus, at 1100 °C, water absorption was 7.9 ± 0.25% for the 15% composition against 5.2 ± 0.20% for the reference. The higher water absorption is most simply explained by additional porosity generated as the organic constituents of the whey decompose during firing, releasing gaseous products. Since neither porosity nor pore size was measured here, this explanation follows from the water absorption data rather than from direct observation.

The results obtained are consistent with Adazabra et al. [18], who found that an increase in the content of organic waste promotes the development of open porosity and increases the water absorption of ceramic products. In the present study, the 15% composition combined the lowest firing shrinkage with water absorption intermediate between the reference and the 20% composition. Whether this corresponds to a finer or more uniform pore structure cannot be established from the present data, since pore size and distribution were not measured. The 20% composition showed the highest water absorption of the three compositions at 950–1050 °C, reaching 12.3 ± 0.15% at 950 °C. No mechanical or durability testing was performed, so the consequences of this for the structural performance of the material cannot be assessed here.

Thus, the introduction of whey has a regulating effect on the processes of porous structure formation in building ceramics. Of the two whey contents examined, 15% gave water absorption closest to that of the reference while showing the largest reduction in firing shrinkage; two non-zero contents are not sufficient to establish an optimum.

*3.3. Structure formation and the mechanism of pore formation*

The shrinkage and water absorption data can be interpreted in terms of the following sequence of processes during heat treatment.

In dairy solids, physically and chemically bound water is released up to about 200 °C; lactose melts and begins to decompose above about 230 °C [40], and whey proteins degrade from about 300 °C with the release of gaseous products such as $CO_2$ and $NH_3$ [41]. Both studies were performed in an inert atmosphere; under the oxidizing conditions of a kiln, the carbonaceous residue is expected to burn out at higher temperatures, which is consistent with the burnout interval of about 200–600 °C shown in Figure 6.

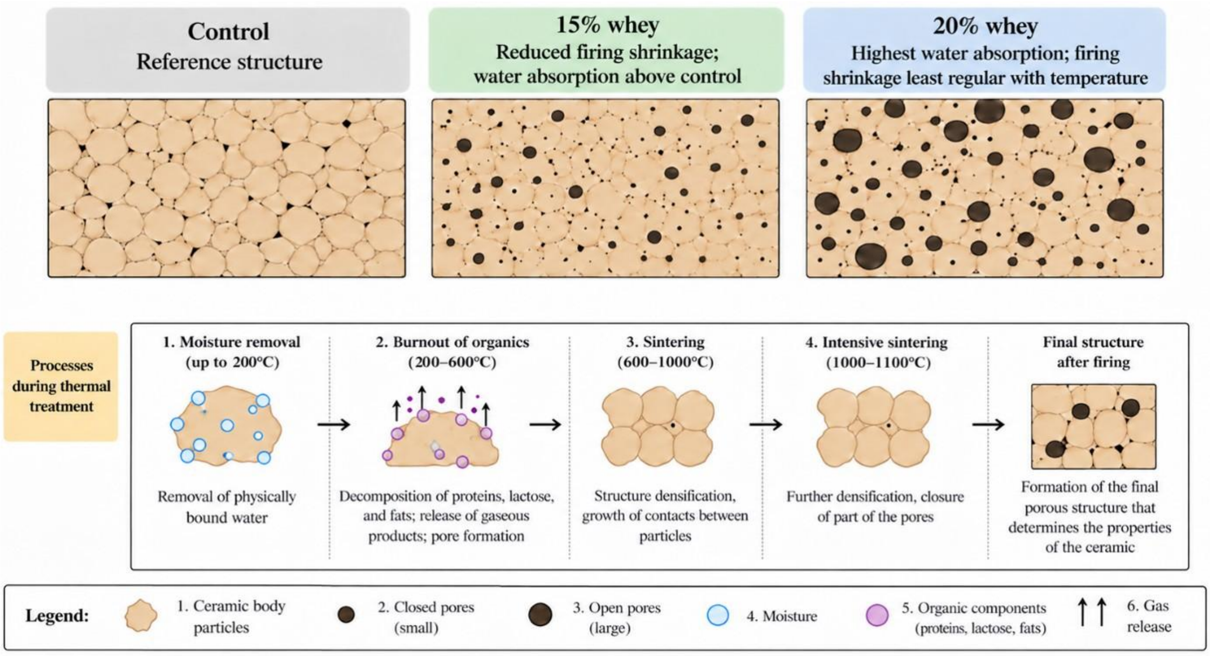


Figure 6 – Proposed mechanism of pore and structure formation in clay ceramics containing curd whey, based on [40], [41] (the pore morphologies shown are schematic representations of the proposed mechanism and were not observed experimentally)

In the present work, no thermogravimetric or differential scanning calorimetry measurements were made, and the temperature intervals shown in Figure 6 are taken from the literature rather than measured on the compositions studied. In the early stages of firing, the pores that form partially compensate for the shrinkage deformations that occur as moisture is removed and the ceramic body compacts. This helps reduce internal stresses and ensures a more stable sintering process. The 15% composition combined reduced firing shrinkage with moderate water absorption, which suggests that sufficient densification was retained after firing. An increase in temperature promotes the development of liquid-phase sintering processes in the mineral phase of the ceramic body. Some pores close due to structural compaction, reducing the material's water absorption. The 15% whey composition nevertheless retained higher water absorption than the reference at every temperature at which both were tested, and the 20% whey composition did so at 950–1050 °C.

These observations agree with Monteiro and Vieira [19], who show that organic additives can regulate pore formation and sintering in ceramic materials. Similar mechanisms have been reported by Eliche-Quesada et al. [21]. At a whey content of 20%, water absorption remained the highest of the three compositions at 950–1050 °C and did not fall at higher firing temperatures as sharply as for the reference. This is consistent with more extensive open porosity persisting after sintering, although neither porosity nor bulk density was measured. Of the two whey contents examined, 15% combined the largest reduction in firing shrinkage with the smaller increase in water absorption. Establishing an optimum would require a wider range of whey contents than was tested here.

*3.4. Comparison with the literature and practical interpretation of the results*

The results obtained are consistent with earlier work on organic waste in clay ceramics [12], [17], [18]. [17], [21], [22] note that the thermal decomposition of organic components contributes to the formation of additional porosity in the ceramic material. According to the literature, the use of organic waste in ceramic bodies allows for a reduction in material density and the regulation of structure formation processes [18], [19], [20]. At the same time, [19], [22], [23] indicate that an increase in the content of organic components can lead to the development of excessive open porosity, accompanied by an increase in water absorption and a deterioration in the performance characteristics of the ceramic material. The present results follow the same trends. Replacing 15% of the mixing liquid with whey reduced firing shrinkage and raised water absorption relative to the reference at every temperature at which both were tested, whereas at 20% whey, water absorption exceeded that of the reference only at 950–1050 °C; the underlying changes in pore structure were not observed directly. The water absorption values obtained can be compared with clause 5.2.4 of GOST 530-2012 [38], which requires water absorption of not less than 6.0% for ceramic bricks other than clinker brick. This is a lower limit, set to ensure an adequate bond between the brick and the mortar. All three compositions satisfied this requirement at 850–1050 °C. At 1100 °C, however, the reference composition fell below the limit (5.2 ± 0.20%), whereas the composition containing 15% whey remained within the permitted range (7.9 ± 0.25%). The higher water absorption produced by the organic additive is therefore not necessarily a drawback: at the highest firing temperature examined, it kept the material inside the range set by the standard, while the unmodified body did not. This comparison was made on laboratory beams rather than on full-size products and does not by itself demonstrate compliance, since compressive strength and frost resistance were not determined; it does indicate, however, the firing temperatures at which the modified compositions would be worth evaluating at production scale.

As in previously published studies [12], [17], the combustion of organic components is accompanied by the formation of additional porosity, which influences the compaction and sintering processes of the ceramic body. Unlike earlier studies, which introduced dairy residues in solid form as a partial clay substitute [26], this work uses liquid curd whey as part of the forming liquid, so that no change to the dry batch is required.

Practically, whey can replace part of the mixing water without any change to the dry batch or the addition of chemical modifiers. At the liquid-to-solid ratio used here, 15% whey in the mixing liquid corresponds to approximately 32 mL of whey per kilogram of clay, or roughly 100 L per 1000 conventional bricks. Whether this represents a meaningful outlet for the whey produced by a given dairy, and whether the emissions from burning out the organic fraction offset the benefit of diverting it from discharge, cannot be judged from the present data. A full life-cycle assessment, of the kind applied to other recycled construction materials [42], would be required before an environmental benefit can be claimed, and no such assessment was carried out here.

*3.5 Limitations of the study*

The scope of this study was limited to two directly measured groups of properties: linear shrinkage and water absorption. Porosity, bulk density, and pore-size distribution were not measured, and no microscopy was performed, so statements about the pore structure of the fired body are interpretations of the shrinkage and water absorption data rather than direct observations. No thermal analysis was carried out, and the temperature intervals assigned to the decomposition of the organic constituents are taken from the literature. Mechanical properties were not determined, so the suitability of the modified compositions for structural applications cannot be assessed from these results. Only two non-zero whey contents were examined, which is not sufficient to locate an optimum dosage. Finally, no environmental assessment was performed, and the resource-saving potential of the approach is therefore stated qualitatively rather than quantified. All tests were conducted on laboratory beams of 100 × 20 × 15 mm and a single batch of clay; the whey was taken from one dairy and sampled repeatedly during the program, so batch-to-batch variation in its composition was not characterized. Extension to full-size products requires separate verification. In addition, individual specimen records were not retained, so no formal statistical testing was possible, and no values were recorded for seven of the composition-temperature combinations (Section 2); comparisons between the compositions are therefore based on mean values.

## 5. Conclusions

The study showed that curd whey can be introduced into a clay ceramic body as part of the forming liquid and that it measurably changes the shrinkage and water absorption of the fired product.

Replacing 15% of the mixing liquid with curd whey reduced firing shrinkage at every firing temperature at which it was measured; at 1050 °C, firing shrinkage was 0.9 ± 0.08% against 1.6 ± 0.08% for the reference, and at 1100 °C, 1.9 ± 0.10% against 2.8 ± 0.12%. Water absorption of the 15% whey composition was higher than that of the reference at every firing temperature at which both were tested: at 1100 °C it was 7.9 ± 0.25% for the 15% composition and 5.2 ± 0.20% for the reference. At this temperature, the reference composition fell below the lower water absorption limit of 6.0%, whereas the composition with 15% whey did not. Increasing whey content to 20% did not reduce firing shrinkage further and produced the highest water absorption of the three compositions at 950–1050 °C, while at 850 and 900 °C its water absorption was lower than that of the reference.

These results are consistent with the generation of additional porosity through decomposition of the organic constituents of the whey during firing. Because porosity, bulk density, microstructure, and mechanical properties were not measured in this work, this mechanism is presented as an interpretation of the shrinkage and water absorption data rather than as a demonstrated finding, and no conclusion is drawn here about the strength or durability of the modified material.

This study forms one stage of a larger program on resource-saving ceramic materials based on organic waste from the food industry. Subsequent work will address the microstructure, phase composition, thermal behavior, and physical-mechanical properties of whey-modified ceramics using scanning electron microscopy, X-ray diffraction, thermal analysis, and standard strength testing.

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## References

[1] I. Ryłko-Polak, W. Komala, and A. Białowiec, "The Reuse of Biomass and Industrial Waste in Biocomposite Construction Materials for Decreasing Natural Resource Use and Mitigating the Environmental Impact of the Construction Industry: A Review," *Materials*, vol. 15, no. 12, p. 4078, 2022, doi: 10.3390/ma15124078.

[2] K. R. Silva, R. R. Menezes, L. F. A. Campos, and L. N. L. Santana, "A review on the production of porous ceramics using organic and inorganic industrial waste," *Cerâmica*, vol. 68, no. 387, pp. 270–284, 2022, doi: 10.1590/0366-69132022683873309.

[3] J. Kirchherr, D. Reike, and M. Hekkert, "Conceptualizing the circular economy: An analysis of 114 definitions," *Resources, Conservation and Recycling*, vol. 127, pp. 221–232, 2017, doi: 10.1016/j.resconrec.2017.09.005.
[4] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, "The Circular Economy – A new sustainability paradigm?," *Journal of Cleaner Production*, vol. 143, pp. 757–768, 2017, doi: 10.1016/j.jclepro.2016.12.048.
[5] A. R. Prazeres, F. Carvalho, and J. Rivas, "Cheese whey management: A review," *Journal of Environmental Management*, vol. 110, pp. 48–68, 2012, doi: 10.1016/j.jenvman.2012.05.018.
[6] G. W. Smithers, "Whey and whey proteins - From 'gutter-to-gold,'" *International Dairy Journal*, vol. 18, no. 7, pp. 695–704, 2008, doi: 10.1016/j.idairyj.2008.03.008.
[7] A. F. Pires, N. G. Marnotes, O. D. Rubio, A. C. Garcia, and C. D. Pereira, "Dairy By-Products: A Review on the Valorization of Whey and Second Cheese Whey," *Foods*, vol. 10, no. 5, p. 1067, 2021, doi: 10.3390/foods10051067.
[8] M. A. Rahman, "Properties of clay-sand-rice husk ash mixed bricks," *International Journal of Cement Composites and Lightweight Concrete*, vol. 9, no. 2, pp. 105–108, 1987, doi: 10.1016/0262-5075(87)90026-1.
[9] C. M. F. Vieira and S. N. Monteiro, "Incorporation of solid wastes in red ceramics: an updated review," *Matéria (Rio de Janeiro)*, vol. 14, no. 3, pp. 881–905, 2009, doi: 10.1590/S1517-70762009000300002.
[10] P. Muñoz Velasco, M. P. Morales Ortíz, M. A. Mendívil Giró, and L. Muñoz Velasco, "Fired clay bricks manufactured by adding wastes as sustainable construction material – A review," *Construction and Building Materials*, vol. 63, pp. 97–107, 2014, doi: 10.1016/j.conbuildmat.2014.03.045.
[11] J. A. Lozano-Miralles, M. J. Hermoso-Orzáez, C. Martínez-García, and J. I. Rojas-Sola, "Comparative Study on the Environmental Impact of Traditional Clay Bricks Mixed with Organic Waste Using Life Cycle Analysis," *Sustainability*, vol. 10, no. 8, p. 2917, 2018, doi: 10.3390/su10082917.
[12] I. Demir, "Effect of organic residues addition on the technological properties of clay bricks," *Waste Management*, vol. 28, no. 3, pp. 622–627, 2008, doi: 10.1016/j.wasman.2007.03.019.
[13] N. Doğan-Sağlamtimur, A. Bilgil, M. Szechyńska-Hebda, S. Parzych, and M. Hebda, "Eco-Friendly Fired Brick Produced from Industrial Ash and Natural Clay: A Study of Waste Reuse," *Materials*, vol. 14, no. 4, p. 877, 2021, doi: 10.3390/ma14040877.
[14] I. Labaied, O. Douzane, M. Lajili, and G. Promis, "Bricks Using Clay Mixed with Powder and Ashes from Lignocellulosic Biomass: A Review," *Applied Sciences*, vol. 12, no. 20, p. 10669, 2022, doi: 10.3390/app122010669.
[15] L. N. Blanca, A. Nilas, B. Benoit, D. B. Hélène, and M. P. Rostand, "Fired clay bricks made by incorporating organic additives: A review," *Case Studies in Construction Materials*, vol. 23, p. e05037, 2025, doi: 10.1016/j.cscm.2025.e05037.
[16] A. Detho *et al.*, "Improvement of engineering properties and environmental impact of fired clay bricks utilizing industry sludge waste," *Scientific Reports*, vol. 15, no. 1, p. 4820, 2025, doi: 10.1038/s41598-025-89147-1.
[17] C. Bories, L. Aouba, E. Vedrenne, and G. Vilarem, "Fired clay bricks using agricultural biomass wastes: Study and characterization," *Construction and Building Materials*, vol. 91, pp. 158–163, 2015, doi: 10.1016/j.conbuildmat.2015.05.006.
[18] A. N. Adazabra, G. Viruthagiri, and N. Shanmugam, "An assessment on the sustainable production of construction clay bricks with spent shea waste as renewable ecological material," *Journal of Environmental Waste Management and Recycling*, vol. 1, no. 2, pp. 36–46, 2018.
[19] S. N. Monteiro and C. M. F. Vieira, "On the production of fired clay bricks from waste materials: A critical update," *Construction and Building Materials*, vol. 68, pp. 599–610, 2014, doi: https://doi.org/10.1016/j.conbuildmat.2014.07.006.
[20] M. Sutcu and S. Akkurt, "The use of recycled paper processing residues in making porous brick with reduced thermal conductivity," *Ceramics International*, vol. 35, no. 7, pp. 2625–2631, 2009, doi: 10.1016/j.ceramint.2009.02.027.
[21] D. Eliche-Quesada, F. A. Corpas-Iglesias, L. Pérez-Villarejo, and F. J. Iglesias-Godino, "Recycling of sawdust, spent earth from oil filtration, compost and marble residues for brick manufacturing," *Construction and Building Materials*, vol. 34, pp. 275–284, 2012, doi: 10.1016/j.conbuildmat.2012.02.079.
[22] L. Zhang, "Production of bricks from waste materials – A review," *Construction and Building Materials*, vol. 47, pp. 643–655, 2013, doi: 10.1016/j.conbuildmat.2013.05.043.
[23] P. Muñoz V., M. P. Morales O., V. Letelier G., and M. A. Mendívil G., "Fired clay bricks made by adding wastes: Assessment of the impact on physical, mechanical and thermal properties," *Construction and Building Materials*, vol. 125, pp. 241–252, 2016, doi: 10.1016/j.conbuildmat.2016.08.024.
[24] A. Khan, A. Ali, M. J. Khattak, L. A. Hume, and T. C. Pesacreta, "Development of Sustainable High-Strength Fired Clay Bricks Using Rice Husk Ash," *Sustainability*, vol. 18, no. 5, p. 2199, 2026, doi: 10.3390/su18052199.
[25] W. Abidi, Y. El Mendili, A. Hajji, N. Laaroussi, K. Annaba, and B. El Haddaji, "Recent trend on the valorization of waste fired clay bricks in construction materials: A review," *Open Ceramics*, vol. 26, p. 100942, 2026, doi: 10.1016/j.oceram.2026.100942.
[26] D. Simón, C. Perez Battistessa, D. Cazzaniga Arduzzo, S. Gass, and A. Cristóbal, "Valorization of sludge from the effluent treatment of the dairy industry as clay substitutes in building bricks," *Construction and Building Materials*, vol. 307, p. 124955, 2021, doi: 10.1016/j.conbuildmat.2021.124955.
[27] "ISO 13320:2020 Particle size analysis – Laser diffraction methods," Geneva, Switzerland: ISO, 2020, p. 59.

[28] "GOST 5180-2015 Soils. Laboratory methods for determination of physical characteristics," Moscow, Russia: Standardinform, 2019, p. 19.
[29] "GOST 3625-84 Milk and milk products. Methods for determination of density," Moscow, Russia: Standardinform, 2009, p. 13.
[30] "GOST 5867-90 Milk and dairy products. Methods of determination of fat," Moscow, Russia: Standardinform, 2009, p. 12.
[31] "GOST 25179-2014 Milk and milk products. Method for determination of protein," Moscow, Russia: Standardinform, 2015, p. 8.
[32] "GOST 3628-78 Milk products. Methods for sugar determination," Moscow, Russia: Standardinform, 2009, p. 15.
[33] "GOST ISO 8070/IDF 119-2014 Milk and milk products. Determination of calcium, sodium, potassium and magnesium contents. Atomic absorption spectrometric method," Moscow, Russia: RIS, 2021.
[34] "GOST 34141-2017 Food products, feed, food raw. Determination of arsenic, cadmium, mercury and lead by the method of inductively coupled plasma-mass spectrometry," Moscow, Russia: Standardinform, 2018, p. 11.
[35] "GOST 26927-86 Raw material and foodstuff. Methods for determination of mercury," Moscow, Russia: Standardinform, 2010, p. 12.
[36] "GOST 3626-73 Milk and milk products. Methods for determination of moisture and dry matters," Moscow, Russia: Standardinform, 2009, p. 11.
[37] "GOST 32892-2014 Milk and dairy products. Method of pH determination," Moscow, Russia: Standardinform, 2015, p. 9.
[38] "GOST 530–2012 Ceramic brick and stone. General specifications," Moscow, Russia: Standardinform, 2013, p. 27.
[39] "GOST 7025-91 Ceramic and calcium silicate bricks and stones. Methods for water absorption and density determination and frost resistance control," Moscow, Russia: Standardinform, 2006, p. 10.
[40] E. Melnikova, E. Bogdanova, D. Paveleva, and I. Saranov, "Sucrose, Lactose, Thermogravimetry, and Differential Thermal Analysis: The Estimation of the Moisture Bond Types in Lactose-Containing Ingredients for Confectionery Products with Reduced Glycemic Index," *International Journal of Food Science*, vol. 2023, pp. 1–10, 2023, doi: 10.1155/2023/8835418.
[41] P. L. M. Barreto, A. T. N. Pires, and V. Soldi, "Thermal degradation of edible films based on milk proteins and gelatin in inert atmosphere," *Polymer Degradation and Stability*, vol. 79, no. 1, pp. 147–152, 2003, doi: 10.1016/S0141-3910(02)00267-7.
[42] Md. U. Hossain, C. S. Poon, I. M. C. Lo, and J. C. P. Cheng, "Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA," *Resources, Conservation and Recycling*, vol. 109, pp. 67–77, 2016, doi: 10.1016/j.resconrec.2016.02.009.

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