The Characteristics and Properties of Rubbing Bricks used for Gauged Brickwork – Part Two

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Abstract

This paper provides a continuation of 'The Characteristics and Properties of Rubbing Bricks used for Gauged Brickwork – Part One', published by Gerard Lynch and Sara Pavía in the March 2003 issue of the Journal of Architectural Conservation. In this, the authors examined the historical background, raw materials, production methods, use, and weathering characteristics of rubbing bricks.

Despite the softness and absence of a protective fireskin, 'low-fired' rubbing bricks are extremely durable. This paper determines the properties and mineralogical composition of these bricks in order to understand their behaviour in response to weathering.

It is concluded that the hardness and durability of rubbing bricks are due partially to the occurrence of mineral cements created by reactive temper. This temper acts in a manner similar to a pozzolan in a hydraulic lime mortar, giving rise to the development of mineral cements through hydraulic reaction. The rubbing bricks show a high level of effective porosity, which influences the production of mineral cements and the overall durability of the bricks.

Introduction

Rubbing bricks, and particularly those made from fine graded and washed brickearth, are soft in comparison with all other building bricks. Fired to a point just below vitrification (900°C), the brick possesses no fireskin common to other fired bricks. Despite their softness and absence of a protective fireskin, these bricks are extremely durable. Evidence of such durability may be seen at various sites where rubbing bricks remain in an excellent condition.

The use of such bricks requires that they be soaked first in clean water to enable them to pick up a fine mortar joint (average thickness of 3 mm, but often less than 1 mm) without the mortar rapidly drying out. Some weeks after this, once the new work has dried out sufficiently, the brickwork is finished by being rubbed smooth using an abrasive, hand-held 'float stone'. This process reveals an initial surface hardening that takes place during the early drying-out period, forming a very thin veneer over the brick faces that is quite difficult to breech. Secondary hardening occurs over a longer period of time (several months) as the brick dries out, affecting its outer face.[1]

Analysis and characterization of rubbing bricks

The performance of a building material in relation to site and environmental conditions is determined by its mineralogical composition and physical properties. A brick is composed of minerals and pores arranged in a certain pattern. The nature of these minerals and the relationships between them will determine key properties such as porosity and hardness, thus dictating the physical and chemical resistance of the material. The nature of their raw materials as well as the firing temperature and firing process greatly affects the final mineralogical composition, porosity, and durability of the material, and therefore the final quality of the brick. In general, high temperatures and/or long firing periods will result in a harder, less porous, and more vitreous brick. Such a brick will generally be more durable than if low fired or fired for a shorter period.

Previous studies of rubbing bricks have been undertaken on the basis of quantitative chemical analysis using X-ray fluorescence (XRF). XRF is a standard and well-established analytical procedure used in the building industry to determine the proportions of chemical elements within a sample brick. Chemical analyses do not, however, identify the actual minerals present, or the relationships between them. For example, typical results from the chemical analysis of a rubbing brick will show a silica (SiO_2) content of 80 per cent. This silica can, however, be present either in the form of sand or silt, in the form of siliceous cements, or forming part of the clay minerals. The properties and ultimate quality of a brick will vary greatly, depending on the form in which silica is present.

Materials and methods

A study of different types of rubbing bricks was carried out with the aim of assessing the properties and performance of these bricks.

In order to understand the properties of the rubbing brick in relation to durability, it is considered essential to determine the mineral composition and texture of the brick with a particular focus on the presence, nature, and arrangement of the mineral cements. To this end, petrographic microscopy and X-ray diffractometry (XRD) were used.

Furthermore, since moisture is directly responsible for many decay processes and mineral reactions that induce hardening, the presence and movement of moisture within the brick were considered important factors. Porosity, water absorption, and water suction were therefore measured according to the relevant standards in order to characterize the moisture transport properties of the rubbing brick.

Ten samples of rubbing bricks from a variety of locations in England and continental Europe, dating from the seventeenth to the twentieth century, were analysed (Table 1).

The brick samples were examined by eye, and using a hand lens and stereo microscope (x100 magnification) to prepare a visual description of the bricks. Brick sections were selected for standard thin-section preparation and petrographic analysis. Thin sections were produced from oriented cuts showing transition areas, taken from both mortared and exposed surfaces. This allowed microscopic identification of minerals and textures at different distances from the exposed brick face and the lime-mortar bed. The exposed surfaces were examined in order to determine the formation of patinas or outer mineral coatings to the brick as a result of environmental exposure. The thin sections were polished to the standard thickness of 20 microns, covered with a glass slip, and examined with a petrographic microscope. Petrographic examination was carried out using both natural and polarized transmitted light.

The mineralogy of the samples was determined by XRD. This method is used to identify mineral phases present in ceramics, and the presence or absence of diagnostic minerals (i.e. new crystalline phases formed during firing, which provide a basis for establishing the firing temperature). XRD also allows the identification of mineral phases of low crystalline state that could not be determined with the resolution of conventional optical methods.

The presence and movement of moisture within the brick samples were determined by measuring the rate of moisture uptake (suction) of a dry

Sample	Age	Provenance	Details
1 London	1682	Gate pier Chiswick Park England	Mortared in place
2 Berkshire	1950	Thomas Lawrence & Sons Bracknell England	Known as 'TLBs' Never used Kept dry
3 London	1856	Arch Weaver's House New Wanstead England	Known as 'Malm Cutter', from Malm clay of London stock bricks Mortared in place
4 Netherlands	C17th	Unknown Church	Mortared in place
5 Belgium	*c.*1500	outside Brugge Belgium	Mortared in place
6 English	1999	Traditional brickyard	Washed clay (London bed) Never used
7 English	1999	Traditional brickyard	Pan ground Not washed (London bed clay) Never used
8 English	1999	Traditional brickyard	Washed clay Never used
9 English	1999	Traditional brickyard	Carving quality rubber Never used
10 English	1999	Traditional brickyard	Never used

Table 1 *Samples of analysed rubbing bricks.*

brick and the amount of water that the brick could hold (absorption).[2,3] The amount of water absorbed by each sample was calculated by comparing the wet mass of the sample to its dry mass.

The volume of pore space in the brick samples (porosity) was also measured. Open porosity,[4] or porosity accessible to water, is the ratio of the volume of the accessible pores to the bulk volume of the sample.

Results

The mineralogical composition of the bricks analyzed by XRD is given in Table 2.

Sample	**1 London**	**2 Berkshire**	**3 London**	**4 Netherlands**	**5 Belgium**
Quartz	XXXX	XXXX	XXXX	XXXX	XXX
Feldspar	XXX	XX	XXX	XX	XX
Calcite	(X)		(X)	X	X
Filosilicates	X	X		(X)	
Diopside	T		XX		X
Wollastonite			X	X	
Haematite	X	X		(X)	
Goethite	X				

Sample	**6 English**	**7 English**	**8 English**	**9 English**	**10 English**
Quartz	XXXX	XXXX	XXXX	XXXX	XXXX
Feldspar	XX	XX	XXX	XXX	XXX
Calcite		(X)			
Filosilicates		X		X	X
Diopside					
Wollastonite					
Haematite	X	XX	X	X	X
Goethite			X	X	X

Table 2 *Mineralogical composition of rubbing bricks.*
Key: XXXX = predominant; XXX = abundant; XX = significant; X =present; (X) = scarce; and T = traces.

According to the results, the analyzed rubbing bricks can be divided into two different groups: haematite-rich rubbing bricks (samples 2, 6, 7, 8, 9, and 10) and calcite/calcium silicate-bearing rubbing bricks (samples 3, 4, and 5). Sample 1 can be included in either group.

The temper (i.e. phases with a diameter greater than 0.015 mm)[5] consists mainly of quartz and feldspar, but also includes rock fragments and mica. It includes predominantly non-plastic phases with greater diameters – rock fragments, single mineral grains of mainly quartz and feldspar, ceramic fragments, and other materials.[6] Cellular structures (probably wood) were also recorded in some of the samples. The temper varies in size between 50 microns and 1.5 mm. The calcium-bearing bricks tend to feature the finest temper (most sized between 50 and 100 microns), whereas the haematite-rich bricks include coarser temper (up to 1.5 mm in sample 10).

Most rubbing bricks contain reactive temper in the form of chert (microcrystalline silica), which has at some time reacted with the surrounding matrix leading to reaction haloes and generation of cements (Figures 1 and 2). Sample 3 contains reactive fragments of volcanic rock as part of the temper. These have reacted with the brick matrix forming the mineral cements. Haematite was also found as cementing patches in the brick matrix.

No clear pattern of superficial cementation was found, with the exception of sample 3. Here, a superficial coating (250 microns in depth, extending locally to approximately 1.5 mm) of cementing mineral

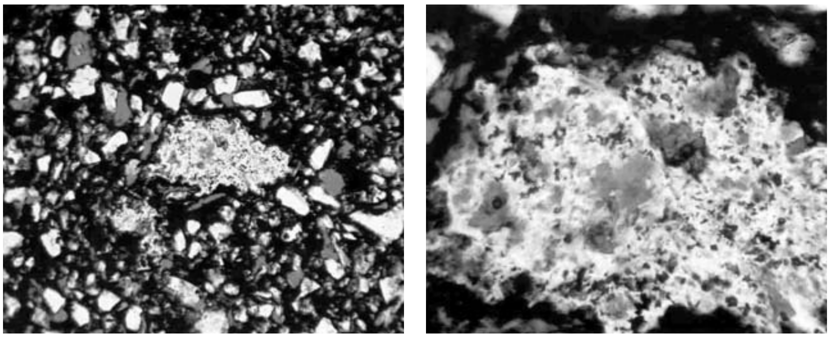


Figure 1 *(left) Microcrystalline silica cement in sample 1, probably generated by hydraulic reaction of thert temper. The photograph (x10 natural light) also shows fine sharp temper and abundant ferruginous cement.*
Figure 2 *(right) Detail of cement in sample 1 (x40 natural light).*

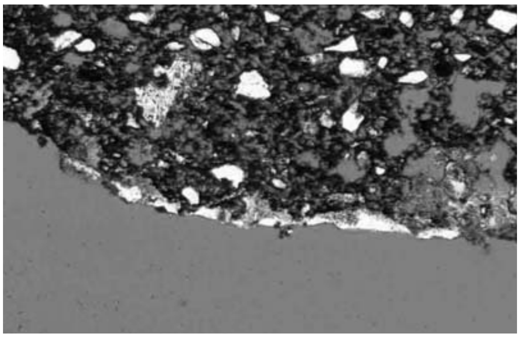


Figure 3 *Superficial cementation in sample 3. Hydraulic cements (probably calcium silicate aluminates) partially replaced by recrystallized calcite. Fine, sharp quartz temper appears in white colour (x10 natural light).*

phases, partially replaced by calcite cement, was recorded on a mortared surface (Figure 3).

In all brick samples the predominant mineral phases obtained by XRD are quartz and feldspar. Although the brick dust analyzed by XRD was sieved, this mineralogical composition largely represents that of the brick temper, where quartz and feldspar predominate.

The rubbing bricks containing calcite and/or calcium silicates (diopside and wollastonite) were probably made from calcareous clay; alternatively, calcite could have been added as a flux to the raw material.

As expected, the mineralogy of the majority of brick samples indicates low firing temperatures. The calcite/calcium silicate-bearing rubbing bricks (samples 1, 3, 4, 5, and 7) contain diagnostic minerals that suggest firing temperatures of 750–900°C.[7] The presence of clay minerals and calcite in most of the other samples also indicates low firing temperatures.

Iron oxide (haematite) and iron oxyhydroxide (goethite) are responsible for the red colour of the rubbing bricks. No iron oxides were recorded in calcium-rich samples 3 and 5. This is consistent with the light colour of these bricks, and previous experimentation on archaeological ceramics.[8]

Physical properties

The porosity, water absorption, and water suction of the rubbing brick samples are given in Table 3.

Even though the haematite-rich rubbing bricks (samples 2, 6, 7, 8, 9, and 10) show a more porous and open microscopic texture (Figure 4), the calcium-bearing bricks (samples 3, 4, and 5) tend to show a higher effective porosity (accessible to water), a slightly higher ability to absorb water by capillary action (suction), and a slightly higher ability for water uptake (absorption) than the haematite-rich bricks (Figure 5).

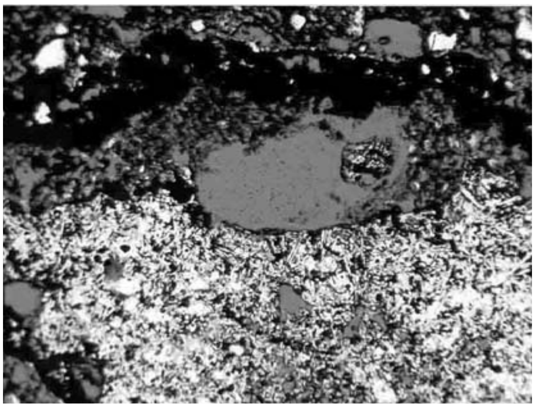


Figure 4 *Volcanic temper showing reaction halo and peripheral, new-formed opaque cement in sample 3 (x10 natural light).*

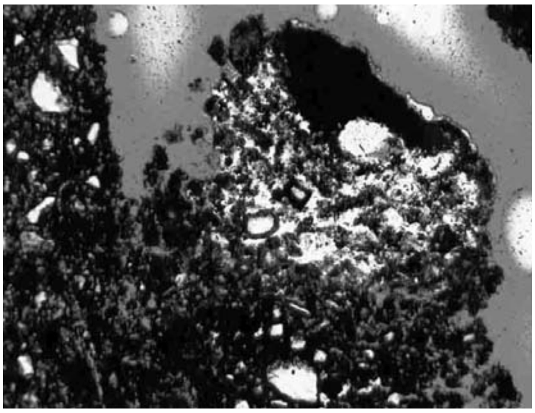


Figure 5 *Hydraulic reaction involving a volcanic temper partially replaced by new-formed, crystalline cement in sample 3 (x10 natural light).*

The average porosity value of the rubbing-brick samples is 35.25±3.77%. This is typical of the range of hand-made bricks presented for reference in Table 4, and compares to the porosity of historic clay bricks and some of the most common building bricks.

According to the results given in Table 3, the average value of water absorption is 15.09±3.12%. This value is lower than the typical values obtained for the historic hand-made range. The average value of suction is 0.43±0.15 gcm^{-2}/min, which is high when compared with the typical values obtained for the historic range.

The rubbing bricks tend to show a high effective porosity, similar to that of the historical hand-made range. They display a slightly higher ability to absorb water by capillary action and a slightly lower total water uptake than historic hand-made bricks.

Sample	**Porosity (%)**	**Water absorption (%)**	**Water suction (gcm^{-2}/min)**
1 London	32.41	14	0.47
2 Berkshire	34.26	12.44	0.19
3 London	42.73	18.6	0.73
4 Netherlands	38.82	17.16	0.52
5 Belgium	38.05	21.24	0.55
6 English	35.65	15.07	0.40
7 English	32.68	14.04	0.30
8 English	32.15	11.99	0.30
9 English	30.15	11.33	0.43
10 English	35.56	15.07	0.44
Average values (±σ)	35.25±3.77	15.09±3.12	0.43±0.15

Table 3 *Properties related to the presence and movement of water.*

Brick type	**Reference values**		
	Porosity (%)	**Water absorption (%)**	**Water suction (gcm^{-2}/min)**
Hand-made range:			
Irish, seventeenth century (average of 10 specimens)	36.15	18.47	0.08
Spanish, seventeenth century (average of 19 specimens)	37.13	21.29	0.22
Machine-made range:			
Gault facing	38.5	–	–
Keuper marl	24.6	–	–
Flettons	34.8	–	–
London stock	48.9	–	–

Table 4 *Reference values for porosity, water absorption, and water suction of historic, hand-made, and machine-made clay bricks.* [9,10,11,12,13]

Durability and hardening by cementation

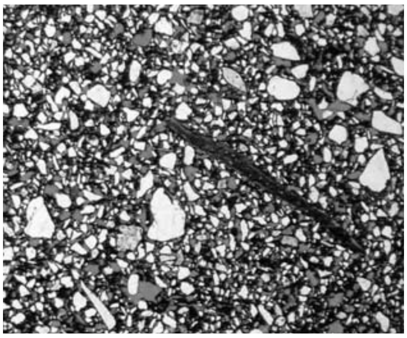
The temperature at which ancient ceramics and pottery were fired varies over a wide range (typically 600–1300ºC), although firing temperatures around 300–400ºC have also been suggested.[14] According to previous work on archaeological ceramics,[15,16,17,18,19] the presence of certain mineralogical associations, diagnostic minerals, clay minerals, and calcite suggest that most historic bricks were fired at temperatures typically under 900ºC.[20,21,22,23]

A lack of firing temperature can adversely affect brick durability by decreasing mechanical strength and enhancing porosity as well as other properties related to the presence and movement of moisture. However, despite the low firing temperatures calculated for the historic range, historic bricks usually possess good durability, and their weathering is limited to local failures induced by specific features, such as the presence of lime particles or coarse chert inclusions.

When compared to historic brick, rubbing bricks have reached a 'high' firing temperature (900°) and cannot be considered underfired. The durability of rubbing brick is what should be expected on the basis of their firing temperature and their selected raw materials, bearing no coarse inclusions or mineral/organic impurities.

Mineral cements give cohesion to clay ceramics, binding the temper and fine-grained matrix. Sintering at a temperature of 750–900ºC has led to the formation of calcium silicates (diopside, wollastonite) in the calcium-bearing rubbing bricks. Some of these new-formed mineral phases have crystallized as anhedral cements in the matrix. As a result of firing, iron-bearing minerals (haematite and goethite) have also formed, cementing patches in the brick matrix. These mineral cements, generated through firing, give cohesion to the rubbing brick.

Apart from those generated through firing, a number of additional mineral cements were microscopically recorded, interspersed in the brick matrix. These arose from reactive minerals contained within the temper of chert and volcanic rock fragments, and are illustrated in Figure 6. The reactive temper was found to be forming reaction haloes and new-formed cements in the surrounding matrix. The petrography of these reaction haloes and cements is very similar to that of hydraulic reactions involving certain types of pozzolans (Figure 7). These have been often observed during petrographic analysis of hydraulic lime mortars.[24]



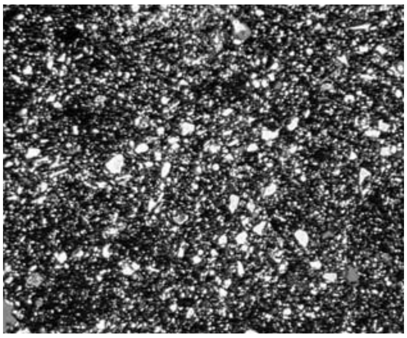


Figure 6 *(left) Haematite-rich rubbing-brick sample 2, displaying loosely-packed microscopic texture with abundant pores and point contacts between temper and matrix (x2 natural light).*
Figure 7 *(right) Calcium-bearing rubbing-brick sample 4, containing a finer temper and displaying more abundant cements and a tightly-packed microstructure (with less coarse pores) than haematite-rich rubbing bricks (x2 natural light).*

The petrography of the reaction haloes and new-formed cements in the rubbing bricks suggests that the temper was probably activated when the bricks were soaked prior to lying. The temper within the rubbing brick – rich in microcrystalline silica and alumina – is acting in a similar manner to a pozzolan in a hydraulic lime mortar. The temper has reacted with lime in the presence of water, forming reaction haloes and cements in the surrounding matrix.

In all cases, the cements occur as local patches with no particular arrangement. No clear pattern of superficial cementation was found in the rubbing bricks, with the exception of sample 3, which displays a coat of mineral cement on a mortared surface. This was probably formed through a hydraulic reaction similar to that mentioned above for the temper.

The great ability of the rubbing brick to absorb water by capillary action and its high porosity suggest an open pore system. This is effective in transporting fluids, allowing free movement of moisture throughout the brick, and therefore not restricting local crystallization of cements from solutions.

The absence of a cementation pattern is not surprising. The occurrence and arrangement of mineral cements in the rubbing bricks resembles closely the arrangement typical of mineral cements – generated through hydraulic reaction – in other porous building materials, such as lime mortars with brick dust as a pozzolan.[25] Here, circulating solutions are highly mobile and hence do not restrict the crystallization of cements which occur as scattered patches in the mortar binder. New-formed mineral cements have been recorded in these mortars in thin section, at variable distances from the ceramic dust.

Comparison of historic and contemporary rubbing bricks

All rubbing bricks produced currently fall into the haematite-rich group, whereas the historic rubbing-brick samples are calcium bearing. The mineral cements are more abundant in the calcium-bearing rubbing bricks than in the haematite-rich bricks. One of the reasons for the lack of cements in the haematite-rich bricks could be that they were never used and therefore not soaked in water. On the other hand, this could be due to the lack of calcium-bearing minerals in the haematite-rich bricks.

Given the lesser amount of mineral cementation, the haematite-rich rubbing bricks should be less resistant to weathering. However, following exposure, both groups show a similar resistance to the weather. The ultimate reason for the resistance of the haematite-rich rubbing bricks could lie in their pore systems. Where abundant, large pores permit the free inward and outward circulation of moisture without damaging the bricks.

Conclusions

Although modern rubbing bricks may be considered to be low fired, they nevertheless have been fired to a sufficiently high temperature to enable sintering to take place. It is this sintering process and the presence of reactive temper, inducing localized cementation, that are the main contributors to the observed durability of the rubbing bricks.

The temper is acting in a similar way to a pozzolan in a hydraulic lime mortar, giving rise to mineral cements through hydraulic reaction. This temper is probably activated when the bricks are soaked prior to being laid on site.

The properties relating to the presence and movement of water are largely similar to those of the historic hand-made brick range. The rubbing bricks tend to show a high effective porosity, similar to that of the historic hand-made range. Rubbing bricks are, however, more efficient in transporting moisture and solutions than conventional clay bricks. When compared to a traditional brick, the rubbing brick shows a slightly higher ability to absorb water by capillary action and a slightly lower disposition for total water uptake. This suggests that the pores within rubbing bricks are well interconnected and very efficient in conducting water. This fact has had an influence on the production of scattered mineral cements and the overall durability of the brick.

The rubbing-brick samples studied can be split in two different groups, according to their mineralogical composition: haematite-rich and calcium-bearing bricks. All rubbing bricks currently produced fall into the haematite-rich group, whereas the historic brick samples studied are mostly calcium bearing.

The haematite-rich rubbing bricks were produced with raw materials low in calcite fluxes; they show a lack of diagnostic minerals, and display loosely-packed microscopic textures with abundant pores and point contacts between temper and matrix. In contrast, the calcium-bearing bricks contain finer temper and display more abundant cements and a tightly-packed microstructure with fewer pores.

Despite their microscopic texture, calcium-bearing rubbing bricks tend to show a higher effective porosity and slightly higher water suction and absorption characteristics than the haematite-rich bricks. This implies that the fine pores of the calcium-bearing bricks are better interconnected and more effective in moisture transport than the coarse, open pores of the haematite-rich range.

Biography

Sara Pavía BSc, PhD

Dr Sara Pavía graduated in earth sciences (applied geology) and completed her PhD in the properties, decay, and conservation of building materials at the University of Zaragoza, Spain. She completed two post-doctoral fellowships, at Trinity College Dublin and the Dublin Institute of Technology, and currently works as a lecturer in the Department of Civil, Structural and Environmental Engineering, Trinity College Dublin. Dr Pavía has lectured on engineering materials at Trinity College Dublin and the School of Architecture, University College Dublin, since 1996. She has co-authored four books and a number of papers; one book – *Stone, Brick and Mortar* – has become a recognized academic reference and working tool for those involved in the building and restoration industries.

Gerard Lynch LCG, CertEd, MA (Dist)

Gerard Lynch is a self-employed historic brickwork consultant, master bricklayer, and author. He followed an apprenticeship as a bricklayer, and over the years gained many awards, including the Silver and Gold Trowels from the Brick Development Association. He is former head lecturer in trowel trades at Bedford College, where he pioneered a revival of interest in gauged brickwork and long-forgotten craft skills. He is author of *Gauged Brickwork: A Technical Handbook* (Gower/Donhead, 1990), *Brickwork: History, Technology and Practice* (Volumes 1 and 2) (Donhead, 1994), and various papers and articles on aspects of his craft.

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Notes

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