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China's brick history and conservation: laboratory results of Shanghai samples from 19th to 20th century

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HIGHLIGHTS

- The first inquiry into the provenance of bricks in the Western heritage of China.
- Identified coal-residue bricks and the potential Russian sources.
- Proposed new perspectives on the modern revolution of China's brick history.
- Revealed the present condition of modern Shanghai's bricks for conservation.

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ABSTRACT

Fired bricks have been used for construction purposes in China for at least two thousand years. Since the mid-19th century the manufacture of bricks has shifted from an old to a new system. The unique Chinese blue brick has been gradually replaced by the European red brick and other modern products. This study focuses on Shanghai as a representative city in that transitional period, aims at addressing the true condition of the modern changes in China's brick history and the heritage today.

The paper presents the first results of an interdisciplinary investigation. Fourteen brick samples and one sample of raw material were studied with regard to the mineralogical, petrographic, chemical, physical, mechanical characteristics, and the maximum firing temperature. It also makes measurements of the presented soluble salts in the altered brick samples.

Preliminary conclusions are drawn with regard to three critical issues: the provenance of the bricks, the hitherto undocumented changes in the manufacturing technology, and the condition of the brick material in terms of conservation.

1. Introduction

In 1925, the Material Test Committee of the Chinese Engineering Society provided some physical-mechanical data of modern bricks from six productive Shanghai brickmaking factories [1,2]. Surprisingly, those rare historical data go against the belief that water absorption usually reduces the compressive strength of a brick, despite the potential yet unrecognisable random errors during the experiment that might invalidate the data [3,4]. Moreover, by the mechanical data, the Chinese engineers stated that the modern new bricks were actually inferior to China's traditional 'blue bricks' even though the latter having suffered over 1000 years of weathering. They ascribed this inferiority to the poor standards of the modern manufacturing system and questioned the well-assumed "progress" of civilisation in technology [2]. This argumentation has attracted very little attention until today. Conversely, engineers, architects, and builders (either Chinese or foreigners) have generally believed that the modern bricks were technically and artistically superior to the old ones, as written evidence and built materials both show, which is in contrast to the 1925 laboratory results in [2]. It is unclear whether or not the properties, deterioration and structural behaviours of the bricks produced in China are compatible with the theories and experiences in the western literature.

The traditional Chinese brickmaking and bricklaying are very different from European methods. Since the mid-19th century the old

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system has shifted to a new system of European mode in both production and use. During the transitional period Shanghai had a very high demand of European red bricks, which makes it be at the vanguard of the epochal shift. Therefore this study focuses on Shanghai, with a broader view on the contacts between China and the West.

Recent studies have revealed the complex mixture of all kinds of old and new blue bricks and red bricks in Shanghai's architecture during the transitional period [3,15]. However there are only a few analytical data about Shanghai cases [9,10]. Limited data about the properties of ancient bricks from other regions of China are published [11,12]. Our study follows these research questions:

- Firstly, the provenance of the bricks. The annually published statistics in the customs archive "Returns of Trade at the Treaty Ports in China," surprisingly, show that among the Chinese port cities Shanghai continuously imported the largest amount of bricks and tiles from foreign countries since 1864, and at least down to the year 1882; recorded origins include Great Britain, USA and Australia. At the same time Chinese blue bricks were exported to foreign countries, e.g. Japan. Where were these imported bricks used in Shanghai?
- Secondly, the progress of civilisation is being brought into question by historians of East Asian science and technology who pay attention to the heavy losses of traditional technology. However the discussions often lack scientific data. We doubt whether the properties of the traditionally-made bricks and the industrially-made modern bricks are comparable. This study thus aims at revealing the true conditions of the bricks, and collecting data for reconstructing the lost traditional technology as well as the real changes and developments in the modern time;
- Thirdly, we broadly observe the deterioration of bricks in Shanghai and the continuous loss of cohesion between the old materials and the restoration interventions. Restorations were often carried out on the surfaces of the brickworks (1–2 cm) after cleaning. What are the causes of the deterioration and the incohesion?

To make traditional blue bricks, a two-stage firing scheme employing oxidizing and reducing conditions was used in traditional kilns. Reducing conditions were achieved through injecting water into the kiln-chambers after an appropriate oxidizing firing, resulting in the 'blue' colour; this technology was still used in China up to the 1990s [13,14]. The reason for the reducing firing has long been an open issue. The literature on oriental ceramics usually hypothesizes that the reducing firing could improve the physical-mechanic properties of the fired ceramics and bricks [5–8].

Focusing on Shanghai, the chronology of the use of the bricks in architecture has been examined [3]. Data on the observable forms of the bricks (dimensions, colours, marks, textures) have also been preliminarily retrieved, and the present work was based on these data.

With regard to the comparable European architecture and analytical data [16–20], the present research deals with the compositional and technical characteristics of the brick samples responding to the above-mentioned three questions. The methodology follows the interdisciplinary strategies piloted in recent studies [21–25]. A determination of the maximum firing temperature was applied in this study [26]. Archival research, industrial records, archaeological and architectural methods were used in combination in order to recognize significant materials from architecture.

2. Materials and analytical methodologies

The samples came from four representative modern buildings, all listed as China's heritage sites. Their construction dates, ranging between 1866 and 1935, cover the main transitional period in the local brick history. (Table 1 and Figs. 1–3, the information of the samples in Table 2).

A sample of raw clay was taken with the help of the local brickmakers from *Nanhui* district on the outskirts of Shanghai City; it was used as a reference to define the origin of other brick samples, the fired brick sample B5 was made from this clay in a traditional kiln. We chose *Nanhui* clay because *Nanhui* is a remarkable place in terms of brickmaking, in either traditional system or modern industry. The famous "*Da-Zhong* Brick and Tile Factory" (1930–1990s) was situated in *Nanhui* and had significant influences from Belgian technology [27]. Sample "6 red" is a decayed fragment taken from the brickwork surface of the St Ignatius Cathedral, and was later revealed to be a restoration mortar by analyses.

Minor/non-destructive methods are ensured as much as possible on site. Most of the samples have mortars and/or plaster attached, from which the outward or inward surfaces of the bricks can be recognized. The exposed bricks in the two churches mainly suffer from salts (i.e. efflorescence), exfoliation and biological colonization.

The following investigations were performed:

- The mineralogical composition was determined on powder using an X-ray diffractometer (XRD) PANalytical X'PertPRO equipped with X'Celerator multirevelatory and High Score data acquisition and interpretation software (Cu anticathode ($\lambda = 1.54$ Å) was used, under the following conditions: current intensity of 30 mA, voltage 40 kV, explored 2Θ range between 3 and 70°, step size 0.02°, time to step 50 s, and scan speed of 0.04°/s.);
- The clay mineral composition was determined on the fraction $<4\ \mu m$ extracted through sedimentation according to Stokes' law [28,29] using a Philips PW 1729 diffractometer;
- The amount of $CaCO_3$ was determined through the Gasometric technique, using a Dietrich Fruhling calcimeter [30];
- The chemical composition was determined using X-ray fluorescence (XRF). Samples were analysed using a wavelength dispersive X-ray fluorescence spectrometer Rigaku ZSX Primus II equipped with an end-window 4 kW Rh X-ray tube;
- The petrographic investigation was carried out through observation in transmitted light of thin sections (30 μm thickness) with an Optical Microscopy (ZEISS Axioscope A1 microscope);
- The grain size distribution of the raw clay was carried out by sieving in order to separate the following fractions: sand ($Ø > 63\ \mu m$), silt ($4\ \mu m < Ø < 63\ \mu m$) and clay ($Ø < 4\ \mu m$);
- Morphological and micro-chemical analyses were performed using an ESEM Quanta-200 FEI environmental scanning electronic microscope. The measurements were performed with an acceleration potential of 20 kV. The main working materials were backscattered electron images at high magnification (from 200X to 400X);
- The presence of salts was measured for the altered samples from the churches, Fourier transform infrared spectroscopy (FT-IR) spectra were collected with a portable Bruker Optics ALPHA FT-IR spectrometer in ATR mode, with a platinum single reflection diamond ATR module;
- The physical characteristics of the bricks were analysed. For each typology, three specimens of $2 \times 2 \times 2$ cm were prepared to determine the water accessible porosity (effective porosity) (Pw%) and the water absorption coefficient (I.C. w%). A Mettler Toledo hydrostatic balance was used applying Archimede's law:

$$V_w = (W_w - W_d)/\gamma_w$$

$$V_a = (W_w - W_h)/\gamma_w$$