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Characterization of Mughal Bricks from Jahangir Tomb, Lahore-Pakistan

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Jahangir tomb, which was constructed during the Mughal era in the subcontinent, is one of the remarkable monuments in the city of Lahore, Pakistan. This particular tomb is representative of Mughal tomb architecture followed by the Persian traditions. In this study, the brick samples were studied employing chemical, mineralogical and micro-structural techniques (X-ray florescence, optical microscopy, SEM-EDS and X-ray diffraction) to determine their characteristics which in turn will help formulate the future conservation strategy for compatible materials. The Mughal bricks showed high content of SiO_2 (60-70 %), Al_2O_3 (14-16 %) and Fe_2O_3 (5.5-7.5 %) with low amounts of Na_2O (1-1.5 %), K_2O (3-3.5 %), MgO (2.3 %) and CaO (2-2.5 %). The bricks also showed low density, high porosity and were produced from raw materials containing calcium poor clays fired at low temperatures. New bricks to be used in restoration works of this tomb should be chemically and physically compatible with the existing masonry. New bricks must therefore be produced by using Ca-poor clays with compatible chemical characteristics, traditional production techniques and heating at low temperatures (*ca.* 850 ºC).

Key Words: Mughal bricks, X-Ray fluorescence, SEM-EDS, X-Ray diffraction, Optical microscopy.

INTRODUCTION

The main goal of conservation and restorations for heritage materials is the compatibility of the intervention materials with the original historic fabric. This requires information and knowledge of historic materials, their construction techniques and the deterioration patterns over the period[1,2]. Incompatible materials can accelerate the deterioration of historic materials and may cause irreversible damages to the structures. This is one of the major present deterioration problem observed in the tomb structures[3].

The Jahangir Tomb was built on the previously laid garden by her wife Empress Nur Jahan during the reign of Emperor Shah Jahan (1627-1658 A.D.)[4]. The historic fabric of the tomb was constructed of bricks and lime mortar masonry with cladding of stone (Fig. 1).

The characteristics of ancient bricks used in the construction of Jahangir Tomb have been determined in order to define the characteristics of the compatible materials, which will be used in the future conservation works to prevent the ongoing deterioration problems.

(a)

(b)

Fig. 1. Jahangir Tomb (a) Rear façade in deteriorated condition (b) restoration works under progress in the heritage site

EXPERIMENTAL

The five brick samples were collected from the walls of the main tomb structure for the identification of their chemical and mineralogical compositions in addition to the microstructural features.

The samples were characterized using the methodology that integrated analytical techniques of X-ray diffraction, SEM-EDS, optical microscopy (on polished surfaces and thin sections) and XRF analysis for the determination of their chemical compositions and mineralogical phases[5,6].

Mineralogical compositions of bricks were identified by using Bruker, AXS D8 Advance powder diffractometer and petrographic polarizing microscope. The microstructures and chemical compositions of samples were determined by using scanning electron microscope (SEM), JEOL JSM 6390 LA coupled with electron probe microanalyzer EDS (EDS, Oxford-1 NCA) on polished sample surfaces which were prepared from vacuum impregnated samples in epoxy resin.

The complete chemical characterization (major and trace elements) was carried out with wave-length dispersive X-ray fluorescence spectrometer (WD-XRF, Axios, PANalytical) equipped with 5 diffraction crystals for ten major (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5) and 21 trace elements (S, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, Pb, Th, U). The XRF was carried out on fused glass-beads made from sample powder with lithium tetraborate in the ratio of 1:5.

RESULTS AND DISCUSSION

Brick is a basic masonry construction unit used from ancient times throughout the world[7]. The collected brick samples were found to have different dimensions due to non standardized traditional ways of bricks making here in the past. The brick manufacturing techniques depend on the supervisors and therefore it was considered as the hereditary gifted knowledge passed on to generations from their forefathers in the Mughal era[8,9]. This is the main reason that the knowledge about the ancient materials and their application techniques which were so successfully used in the past has now disappeared without any documentation in our part of the world.

Mughals used brick masonry jointed with the lime mortar (Fig. 2a) as the main construction unit which afterwards was usually cladded with red sandstone and white marble (Fig. 2b), characteristic geometric patterns of Mughal style (Fig. 1).

(a)

(b)

Fig. 2. Jahangir Tomb (a) Mughal bricks used with lime mortar in historic construction (b) new bricks for restoration works in the heritage site

Optical microscopy of investigated brick samples (on thin sections and cross sections) suggested the low firing temperature during their manufacture as high temperature phases (mullite and crystoballite) were not identified in these samples. The presence of quartz with feldspar, Illite/Muscovite, hematite and very few distorted calcite crystals further elaborated the variable and unstable firing temperatures[10].

The mineralogical phases identified by XRD analysis showed that the Mughal bricks were mainly composed of quartz (SiO_2), albite ($NaAlSi_3O_8$), K-feldspar, hematite and illite/muscovite (Fig. 3). Calcium compounds were observed in traces (Fig. 4) indicating calcium-poor raw materials used for manufacturing these bricks[11-14]. The absence of high temperature products (mullite and cristoballite) peaks shows that the temperature did not exceed 900 ºC.

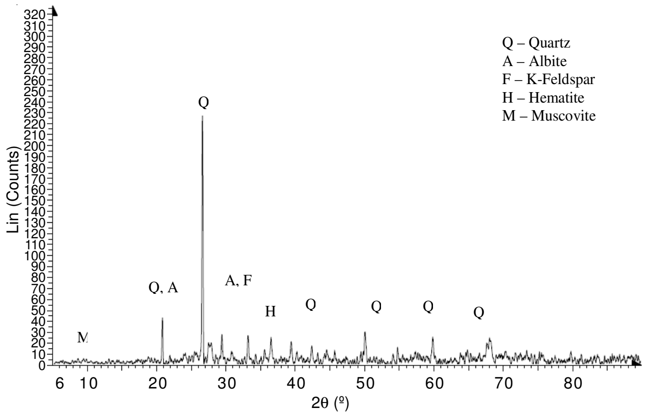

Fig. 3. XRD pattern of the Mughal brick sample (BSJT-1) with peaks of quartz, albite, feldspar, hematite and muscovite minerals

The diffraction peaks of quartz were the most intense in all the samples. Quartz normally transforms into tridymite at 870 ºC but due to the slow reaction rate, quartz persists above its theoretical stability range when the constant high temperature is not maintained[15]. The presence of feldspar mineral group in all the samples also indicates the similar temperature range (below 950 ºC)[16]. Hematite was also found further confirming low and unstable temperature firing of bricks characteristic of low-calcium clays used as raw material[15-17]. The presence of illite/muscovite transitional stage also supported this fact[18].

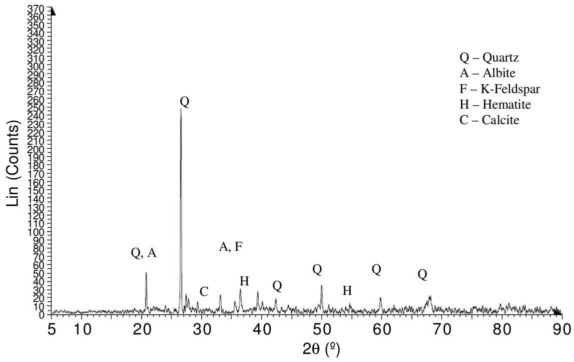

Fig. 4. XRD pattern of the Mughal brick sample (BSJT-4) with peaks of quartz, albite, fedspar, hematite and muscovite minerals with a very low peak for calcite

The illite/muscovite transforms into anhydrous form (dehydrated lattice) retaining its micaceous character between 200-600 ºC. The anhydrous modifications finally transforms into new phase (mullite) above 850 ºC which stabilizes between 1000-1200 ºC[19-21]. The absences of high temperature products are also indicative of illite/muscovite presence not being completely transformed into mullite. The low and weak peaks for calcite were also found in few samples. Additionally, a diffuse band between 20 and 30º 2θ was also observed which showed the presence of amorphous substances formed during vitrification and glass formation starting at 850 ºC[10]. This is further supported by the soil mineralogy of the Shahdara which showed that the soils were composed of clay, silt and fine sand fractions. The A and B horizon soils showed mixed mineralogy consisting of clay mineral mainly illite and the minerals in silt and fine sand fraction were quartz, feldspar and mica[22,23]. The estimated firing temperature ranges of the Mughal bricks were found to be 850-900 ºC[15-17].

The chemical composition obtained from XRF analysis clearly depicted and complemented the mineralogical composition in that the Mughal bricks were composed of high amounts of SiO_2, Al_2O_3, Fe_2O_3 and considerably low amounts of Na_2O, K_2O, MgO and CaO as shown in Fig. 5. The presence of low calcium in their composition shows that calcium poor clay was used in the manufacturing of the bricks as discussed above[5,6,21]. The trace elemental composition (Fig. 6) comparison of sample bricks with the Shahdara soils further established their manufacture from the locally available raw material sources[22-25].

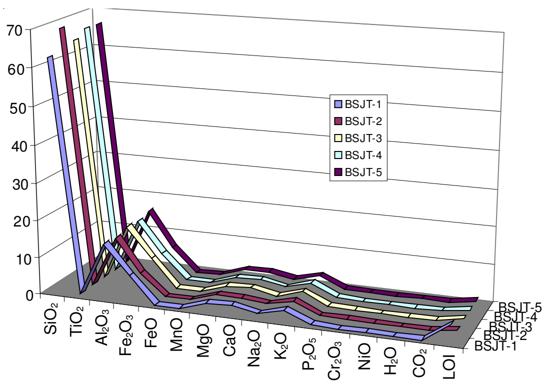

Fig. 5. The chemical composition (major elements) of Mughal bricks showing high amounts of SiO_2, Al_2O_3, and Fe_2O_3 with low amounts of Na_2O, MgO and CaO from Jahangir Tomb

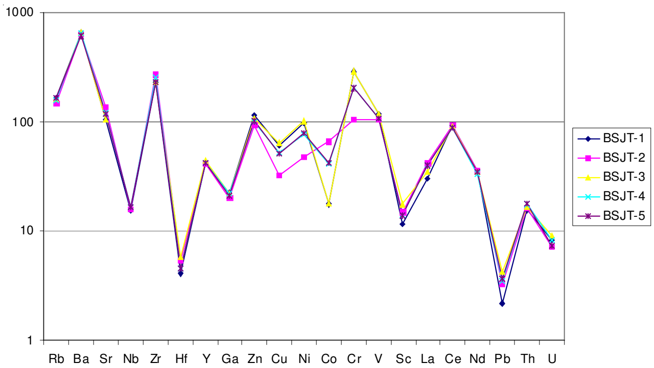

Fig. 6. The trace elemental composition of Mughal bricks sampled from Jahangir Tomb, Lahore-Pakistan

The elemental compositions (Table-1) and microstructural studies of the bricks were determined by SEM-EDS analysis. Fig. 7 showed further elaborating the mineralogical and chemical compositions. The brick microstructure studies also revealed the inconsistent firing temperatures which results into differential heating of the raw bricks and generation of amorphous substances (as also detected in XRD) as observed in different samples[26,27]. The textural studies showed different zones of clay minerals transformation at various stages with the same chemical nature as documented by EDS spectrum[28,29].

TABLE-1
ELEMENTAL COMPOSITIONS OF MUGHAL BRICKS DETERMINED BY SEM-EDS

Samples	Na_2O	K_2O	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
BSJT-1	3.03	3.1	1.42	1.61	7.63	20.1	63.01
BSJT-2	3.76	5.13	1.75	1.55	7.99	17.71	62.11
BSJT-3	3.89	4.57	1.32	2.02	8.15	18.33	61.72
BSJT-4	3.78	4.67	1.44	1.71	8.75	16.76	62.89
BSJT-5	3.07	5.17	1.57	2.1	7.99	18.59	61.51

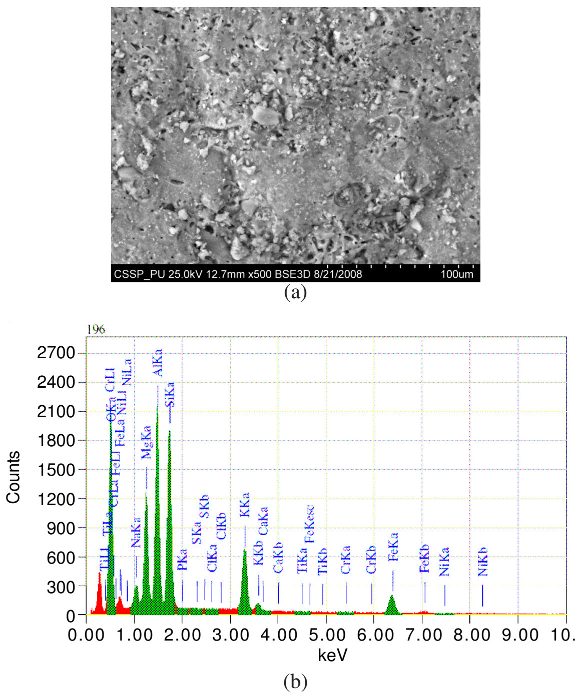

Fig. 7. Mughal Brick sample (a) BSE-SEM micrograph (b) EDS spectrum of brick sample showing high amounts of silica, alumina and iron oxide with low amounts of soda, potash, magnesia and negligible calcium oxide from Jahangir Tomb

These results revealed the traditional brick manufacturing technology used during the Mughal period and also helped in estimating the firing temperature range for these bricks. One of the main reasons for differential heating is the fuel used for brick manufacturing in that period[8,9]. The fuel used in the kiln for firing was dry grass, wood, cow-dung cakes and coal that generate the inconsistent flame which cannot be regulated. The temperature of the kiln was dependent on the availability of the fuel and was estimated without thermometers with the color of the flame[3,4,9]. The firing process usually have five stages starting from water smoking completed at 120 ºC followed by decomposition of vegetable matter at 200 ºC. Then around 700 ºC carbon and sulphur in the clay burned by the oxidation. The vitrification starts at 800 ºC renders the brick into hard stone like material and the temperature goes up to 900 ºC[8,9]. The color and texture of the final brick depends on the iron oxide content of the clay and the firing conditions. The majority of the bricks were fired between 850-900 ºC to get red colour because beyond that it changes into dark red or purplish tone. It is also one of the indicators of temperature used for firing the Mughal bricks which were reddish in tone[25]. The whole process of brick manufacturing was supervised by Emperor appointed supervisor to make high quality bricks for the construction of Mughal buildings.

Conclusion

Mughal bricks chemical and mineralogical characterization showed that bricks were mainly composed of SiO_2, Al_2O_3 and Fe_2O_3 with low amounts of Na_2O, K_2O, MgO and trace amounts of calcium compounds. These results also characterized them of low density and high porosity under scanning electron microprobe.

The chemical composition (major and trace elements) indicated locally available raw materials were employed for the construction of these historic monuments. The scanning electron microscopy with EDS (spot analysis-chemical) also confirmed the XRD results for using the Ca-poor clays for the brick manufacturing.

The estimated temperature range of 850-900 ºC based on minerals transformation and microstructure studies on brick samples also shed light on the traditional brick manufacturing technology used in the glorious Mughal era.

This characterization would help in preparing the compatible materials for the restoration with similar proportions and possibly the same materials (as locally available raw materials were used in the original construction) to avoid incompatible deformations with the historic materials.

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