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IDENTIFICATION OF MORTAR COMPONENTS USED IN JAHANGIR'S QUADRANGLE LAHORE FORT, LAHORE

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ABSTRACT

Built environment is a valuable asset and portrays the cultures and norms that evolved through ages. Because of its unmatched historic value, the Lahore Fort Lahore has been declared as protected and significant building in the World Heritage List since 1981 and hence being protected by UNESCO. It has also been noted that improper conservation techniques has resulted in damage to the structures and craftsmanship. So, in order to save our time and money, it is mandatory to analyze the original material to know its constituents as well as the application techniques A study was conducted to examine the materials used in the Mughal-era structure, Jahangir's Quadrangle, at Lahore Fort, Lahore. Both invasive and non-invasive techniques were applied to explore the constituents of original mortar sample. Analysis through X-Ray Diffraction and Petrographic studies of the mortar samples of Jahangir's Quadrangle identified mortar components as burnt lime and fine Ravi sand. Disilicates were also detected in the mortar. It was also explored through investigation that the Kankar found in the area near Lahore consisted of lime and sandy clay with other impurities in the ratio of 70% and 30%. The presence of impurities in the mortar is vital to provide it with appropriate bonding strength naturally. In addition to the natural, the other causes of deterioration of materials found in Jahangir's Quadrangle were through the polluted environment due to the emissions of SO_3, NO_3, CO_2 and fluorides in the dust due to vehicles. After various analytical techniques, the conservation mortar composition was determined to be a mix of sand, fine kankar, and coarse kankar in a ratio of 1:1.5:1.5.

Keywords: Environment, Cultures, X-Ray Diffraction, UNESCO, Jahangir's Quadrangle, World Heritage

Introduction

A historic building exudes sense of wonder and develops curiosity and about the people, values and culture that created it. Today the civilized opinion is agreed that all outstanding monuments and archaeological sites in the world are the legacy of the entire human race and the countries possessing them are not more than their trustees. They are thus responsible for their proper preservation [1]. The damage done by wrong conservation of stone and brick masonry of historic buildings has sparked interest of researchers and conservationists in the recent decades. This has also lead

to renewed interest in the traditional lime mortar and various techniques of analysis to identify its components. The basic objective being that the original mortar becomes compatible to the newly applied lime mortar [2]. Hence, it has become mandatory to deeply explore the ratio and constituents of historic mortar to be used in the historic building [3].

As given by Feilden[1], [4] "Conservation is the process of preserving the built heritage whether it is a historic monument or site or cultural property created in the past. This process ensures to keep this heritage in a state that it remains a valuable source of knowledge, for the coming generations".

Location of Lahore Fort:

Lahore is an important historic city, situated in the heart of Punjab province. Its history dates back to 1000 B.C. Today, it is adorned with bustling bazaars and diverse crowds with captivating colors. The citadel of Lahore Fort is situated to the north western side of Walled City and left bank of River Ravi [5]. The site was ideally located as along north south it ran along River Ravi and towards East West, it connected Kabul to Delhi, see figure 1. Lahore Fort, protected by UNESCO has been in World Heritage List since 1981 [6]. Basically it was built for royal residential purpose and is a sign of amazing Mughal architecture. Through the art kept alive in this Fort even after centuries, it eloquently speaks of the competency of the architects, designers, constructors, and planners who contributed to its construction and durability [7].

Figure 1: Location plan of Lahore Fort in Lahore. Courtesy: LDA, Lahore

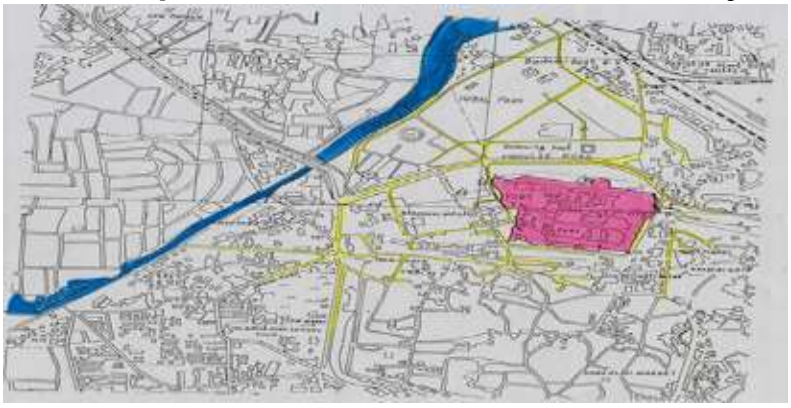
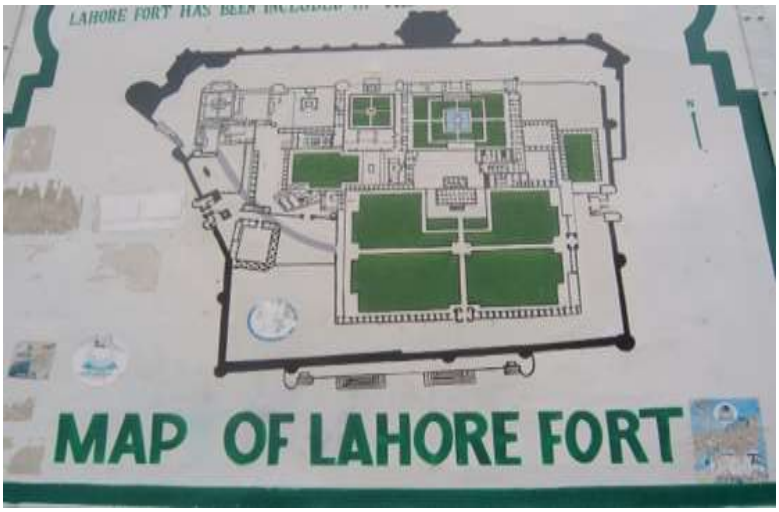


Figure 2: Guide Map of Lahore Fort Courtesy: Lahore Fort administration

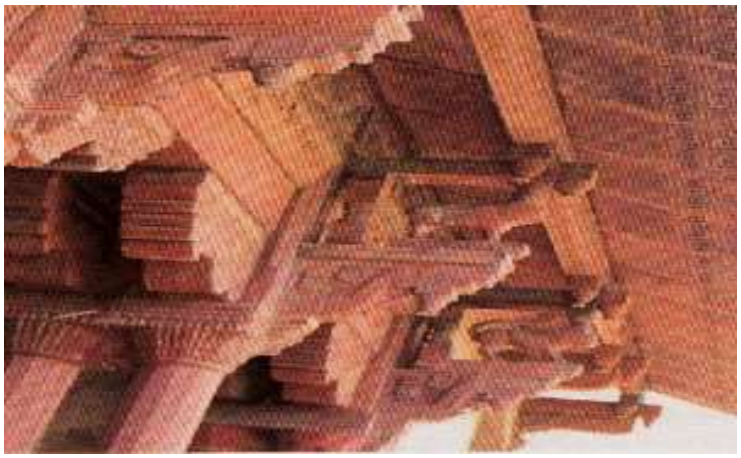


Emperor Jahangir's contributions to the Lahore Fort:

Jahangir was fourth Mughal Emperor who ruled from 1605- 1627 in India and one of the remarkable structures in Lahore Fort was constructed during his reign. The construction of Jahangir's Quadrangle was initiated by Jalal ud Din Muhammad Akbar, who was the third emperor in the hierarchy of Mughal Empire, and it was completed in the reign of Emperor Jahangir in 1618 AD with an expenditure of Rs.7 lakhs. At that time. As the Emperor Jahangir accessed the throne, he focused on establishing his legacy through grand architectural projects, particularly within the Lahore Fort which included Jahangir's Quadrangle, Kala Burj and Makatab Khana. These buildings were masterfully designed by Khawaja Jahan Mohammad Dost who was a well-known Architect and Designer of the Agra Fort Palace in Agra. [8]. the final touches for aesthetically appealing effect were imparted under the supervision of Architect, Abdul Karim Mamur. On several occasions, while visiting these places, Jahangir, has referred to these remarkable residences and soul stirring sitting places in his memoirs in 1620 [9].

Figure 3: Jahangir's Quadrangle Eastern Dalan (Photo by the Researcher 2005)

Figure 4: Close view of Jahangir's Quadrangle (Photo by the Researcher 2005



Significance of Research:

Over the past few decades, the techniques for analyses of mortar have advanced significantly and have become a standard practice in conservation efforts [10]. A

serious concern over this issue has evolved because of masonry erosion resulting in degradation of the invaluable historic architectural monuments, which can lead to severe harm and danger to their existence. [11]. So, in order to save our time and money, it is mandatory to analyze the original material to know its constituents as well as the application techniques. Only through this technique can we suggest the appropriate mixes and ratios for repair of masonry that align with the originally used mortar. Samples of past workmanship should be collected and used for reference. Furthermore, conservation craftsmen must understand the original setting and application methods of these materials. [12]. The newly applied conservation material must not only be visually and physically compatible with the un-weathered original mortar, but also wear away in a similar manner over time [13]. Hence, this is the only suggestive way to conserve our monumental assets and cultural heritage.

Such in-depth information is also significant for the architects, conservationists, historian, scholars and students for the construction, conservation and preservation of our built heritage. In addition to all this it will develop an understanding of the fact as to why such buildings are still intact, even after the passage of 400 years.

Research Methodology:

To start with the research, firstly, a study of the published Mughal period literature about lime mortar was carried out. Being the primary component by volume in mortar, its gradation was explored through tests in the laboratory. A specific area of the wall of Jahangir's quadrangle was selected to get the original mortar sample for visual and instrumental tests from established laboratories. When collecting the mortar sample from the structure for testing, it was ensured that it was genuine and not from the renovated part of the building. The invasive techniques applied were petrography, XRD/SEM, and micro-photography [14]. Whereas, the non invasive techniques applied for qualitative and quantitative analysis were visual inspection, light microscopy, and wet chemical analysis. Finally, in the light of the analysis, conclusions were drawn regarding the ingredients and proportion in the lime mortar to be used for the conservation and repair of Jahangir's Quadrangle.

Detailed Process of testing:

Qualitative Composition:

To obtain an optimal view of the sample for visual examination, the sample was firstly cleaned thoroughly, then rinsed with water, and finally wiped with dilute hydro chloric acid (HCL) solution [15].

Quantitative Analysis:

Firstly, sample was placed on a transparent graphical sheet with a scale in millimeters. Then the total covered area was calculated along with the area covered by different materials, e.g. brick, slag, kankar, marble pieces etc. The area covered by the constituents of mortar was subtracted from the total covered area to get the area of the lime mortar in millimeters [16] Following results were obtained for the sample collected:

Figure 5: Sample collection area from Jahangir's Quadrangle Western dalan (Photo by the researcher)

Figure 6: Mortar Sample no: 8 from Jahangir's Quadrangle (Photo by the Researcher)

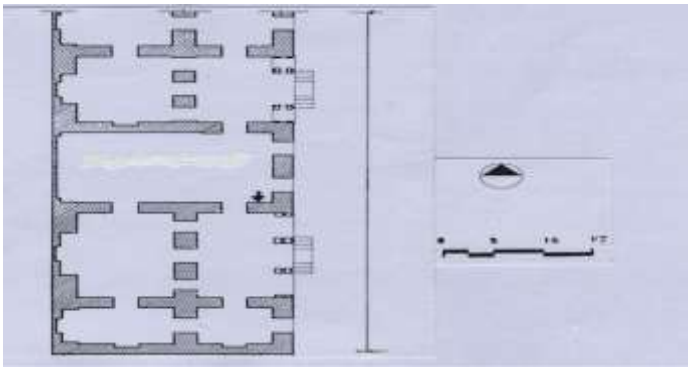


Table no 1: Quantitative Analysis of mortar sample from Jahangir's Quadrangle (Western Dalans)

Total area of the sample = 3000 mm^2 (Author's own construct)

No	Material	Quantity =3000mm^2	Percentage
1	Brick	49mm^2	1.6 %
2	Kankar	52 mm^2	1.73 %
3	Carbon	4 mm^2	0.133 %
4	Soft Chalk	94 mm^2	3.1 %
5	Lime	2801 mm^2	93.3 %

All the lime is dissolved and only residual sand and impurities are left behind as the sample is washed in 20 % dilute HCL.

Table no 2: The ratio and percentage between Sand and Lime ($CaCO_3$) in Jahangir's Quadrangle mortar sample:

Mortar 100%	Residual Wt.X100 Actual Wt.	=Residual Sand %	Mortar 100%	=$CaCO_3$weight Loss %	Ratio
100	12.341 X 100 / 28.193	44%	100	66%	1:1.5

Table no 3: The proportion and percentage of sand and quicklime (CaO) in the mortar sample from Jahangir's Quadrangle.

-Mortar 100%	Atomic weight of CaO X Loss in weight 100.	=CaO %	=Sand %	Ratio
100	**56 X 66 / 100**	**33.00%**	**67.00%**	**2.0:1**

Table no 4: The proportion and percentage of sand and slaked lime ($Ca(OH)_2$ in the mortar sample from Jahangir's Quadrangle.

-Mortar 100%	Atomic weight of $Ca(OH)_2$ X Loss in weight 100.	=$Ca(OH)_2$ %	=Sand %	Ratio
100	**74 X 66 / 100**	**48.84%**	**51.16 %**	**1.1:1**

Table no 5: Sand and Lime ratios and their comparison for Conservation in Jahangir's Quadrangle mortar sample

Sand to Lime ratio	Sand to Quick Lime ratio	Sand to Slaked Lime Ratio
1:1.5	**2.0:1**	**1.1:1**

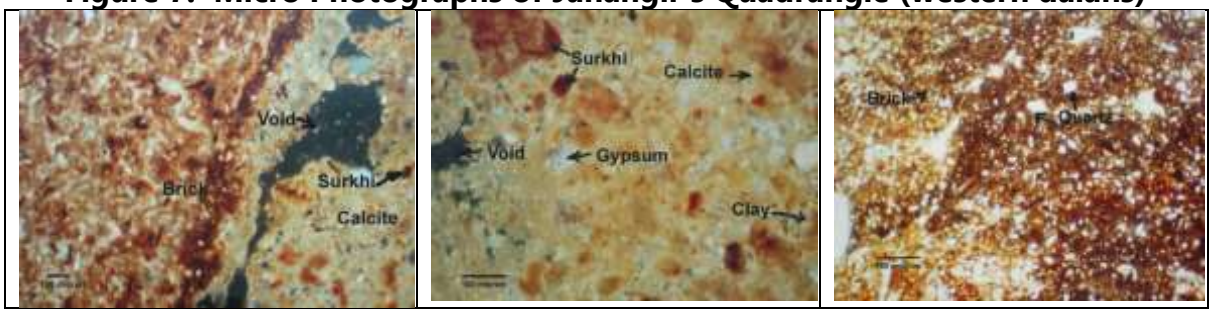
Table no 6: Ratio and range between fine and coarse kankar lime to prepare mortar

Ratio and range between fine (burnt) and coarse (unburnt) kankar lime to prepare mortar
1.0 to 1.5 : 1.0 to 2.0

Analysis of Micro-photographs of Mortar Sample from Western Dalan of Jahangir's Quadrangle

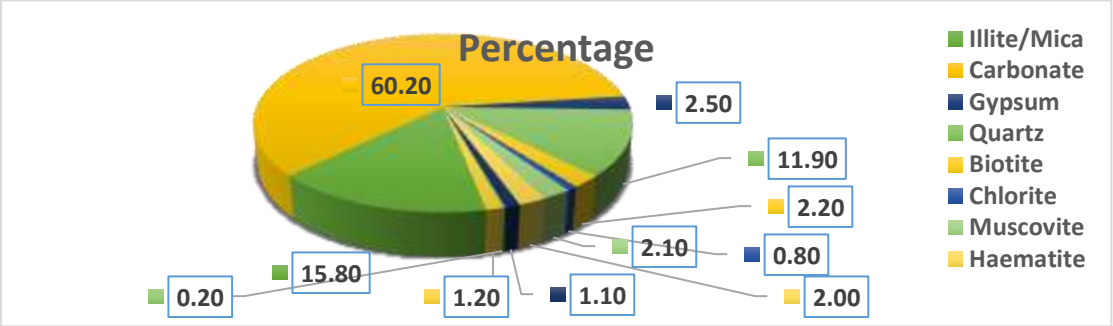
Micro photographic analysis of the mortar components in the sample of 100 microns was found to be : surkhi, calcite, bricks, gypsum and clay, see figure 7.

Figure 7: Micro Photographs of Jahangir's Quadrangle (western dalans)



Petrographic Polarizing Microscope was used to study thin sections of mortar samples and after detailed analysis, following results were attained.

Figure 8: Percentage of minerals in mortar sample from Jahangir's Quadrangle Courtesy: Petrographic and Materials Laboratory Postgraduate Centre for Earth Sciences Punjab University Lahore

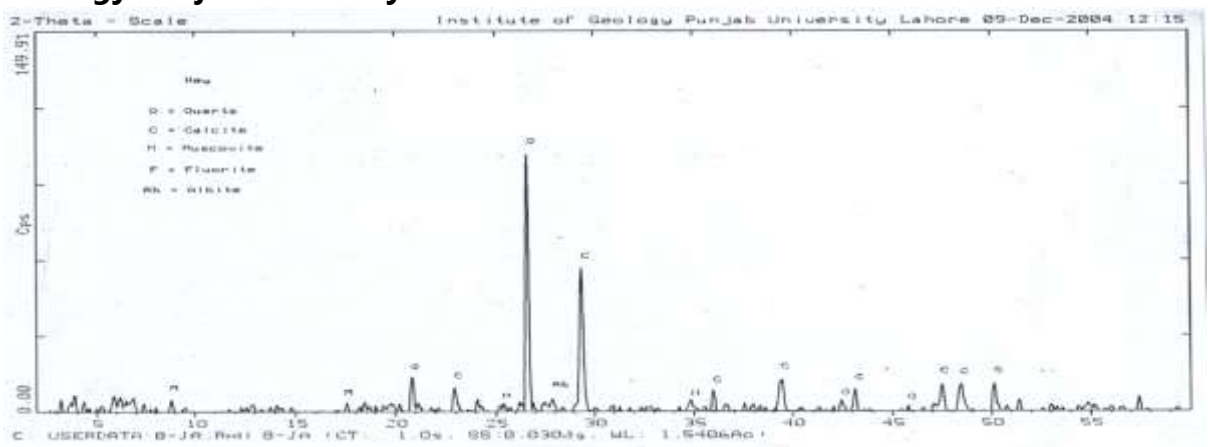


X.Ray Diffraction results of mortar sample from Jahangir's Quadrangle Western Dalan

A sample of mortar was studied through X. Ray Diffraction technique:

As revealed by the analysis, the main components of the mortar were calcite and quartz. Minor accessory minerals detected were: illite/muscovite, albite and gypsum.

Figure 9 : XRD of Jahangir's Quadrangle (Western Dalans) Courtesy: Institute of Geology Punjab University Lahore. Dec. 2004



Analysis of X. Ray Diffraction

A mortar sample was analyzed using X-ray Diffraction (XRD). The results revealed that the primary components of the mortar were **calcite and quartz.** Minor accessory minerals detected were: **illite/muscovite, albite and gypsum.**

It appears that gypsum and flourite were secondary minerals found as orthopogenic agents**. .** Gypsum, in particular, may be associated with sulfur oxides (SOx) emitted by nearby vehicles, which could have settled in the vicinity of the Lahore Fort, leading to its incorporation into the mortar over time**.**

Details of Results

The most prominent material found in the sample was micritic calcite with small amounts of variable mixtures of calcite spar.

Fine sand and kankar in variable amounts in the form of small pebbles were also found embedded in the cement. Some small pieces of brick and little sand was also detected. Quartz being the major ingredient of sand, was encountered in addition to other minerals like biotite, muscovite, zircon argillite etc.

The investigation proved that the sand from the mortar sample was comparable with the sand from the River Ravi sand were comparable that both were comparable with respect to texture as well as mineralogy. This indicates that Ravi Sand was used in the form of fine grain sand in the mortar sample. Gypsum was also detected in the sample but it was in lesser amount because of some insignificant occurrence. All this proves that brick pieces, fine and coarse kankar, small amount of slag and some marble pieces play their role in developing the required gradation in the mortar.

Need for regional guidance and codes of practice

There is a need for regional guidance notes and codes of practice which are helpful and informative to the users of building limes. These need to consider local differences such as climate, available limestone types, aggregates, pozzolans and available skills. Above all, standards must address the needs of users as well as providing practical guidance in response to specific regional demand.

Final Suggestions:

Through different megascopic and microscopic analysis, the constituent ratios of brick mortar and stone masonry were found as follows:

Proposed Ratios and Range for Lime Mortar used in the Conservation of Jahangir's Quadrangle.

- Kankar lime constitutes Hydraulic Lime (NHL) + Sand + Surkhi etc. having sand and clay in the form of impurities.
- When Kankar is burnt at 700-900ºC in a kiln, (CaO) is produced. In this case, the lime gives out CO_2 leaving behind CaO or quick lime. The mason's mortar is produced by mixing quicklime, sand, or aggregate and water in appropriate ratios and is used to bind bricks, blocks or stones together.
- Immediately after calcination, the quicklime is gradually added to water in pits or containers. After that the slaked lime is stirred and raked continuously until the visible reaction subsides.

Proposed Range of Lime Mortar Ratios used for the Conservation of Jahangir's Quadrangle at Lahore Fort.

Table no 7: Recommended Ratios and Range of Sand, Coarse and Fine Kankar Lime used for the Conservation of Jahangir's Quadrangle.

Sample Area	Mortar constituents ratio Sand : Coarse Kankar Lime: Fine Kankar Lime
Jahangir's Quadrangle	**1.0 : 1.0 to 2.0 : 1.0 to 1.5**

- The analysis confirmed that Kankar from Punjab consists of approximately 30% clay and 70% calcium carbonate which also includes sand and other impurities. Due to the presence of impurities in Kankar lime, it is recommended to use a combination of both coarse and fine Kankar to form the required mortar.
- It has also been established that not only the ratio of constituents but the quality of raw materials, method of production and standard of workmanship play a vital role for the achievement of final quality. In addition to that, it is also important to understand the local weather conditions to determine the final specifications. There is a possibility that the local materials may not be standard but are most suitable when appropriate preparation methods and their application are incorporated.
- Variable setting properties can be obtained between pure and hydraulic lime
- It is essential to note that, regardless of how comprehensive a specification may be, there is no substitute for skilled, precise and committed workmanship. The selection of the most appropriate method for using lime should always adhere to local regulations and guidelines.

Recommendations:

- The scope of building craft skills in conservation encompasses a wide range of activities, from basic repair and maintenance of residential properties to the most complex and intricate restoration projects. Achieving high-quality workmanship requires proper training, consistent practice, and public recognition of the value and status of the craftsman.

Good workmanship is closely tied to fair compensation for a day's labor. Craftsmen bear primary responsibility for the quality of their work, which can be further enhanced through incentives such as overtime pay and production bonuses. These factors not only motivate craftsmen but also ensure that their skills are appreciated and utilized to their fullest potential in conservation efforts.

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