

# ANALYTICAL STUDY OF THE BRICK TILES USED IN MUGHAL'S AND LATER PERIODS IN THE HISTORICAL SITES OF PUNJAB PAKISTAN (A CASE STUDY OF AKBARI MAHAL, AKBARI GATE AND ROYAL KITCHEN LAHORE FORT)

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## Abstract

Mughal's (1566 A.D-1674 A.D), Sikh's (1799 A.D – 1839 A.D), British (1846 A.D – 1927 A.D) and Post- Independence periods (1947 to date) are the most important one in the Archaeology of Pakistan in which brick tiles are extensively used to construct the monuments all over the Pakistan and also within the Lahore Fort complex (Mughal Period) and then to preserve/restore (Sikh's, British and Post-Independence periods) several times. The properties of the brick are important to understand before any repair/renovation work. Three monuments named as Akbari Gate, Akbari Mahal and Royal Kitchen within the complex of Royal Fort Lahore are selected. All these selected monuments have brick tiles specimens of each period, which are Mughal, Sikh's, British and Post-Independence one. Care is taken while extraction of brick tile specimens under the supervisions of historians and conservators with the help of hammer and chisel. The brick tiles are identified by well-established techniques of testing, i.e., chemical analysis, water absorption, efflorescence, crushing strength. Finally, tables of comparison and graphs are developed with respect to these variations, to check the % of sulphates, chlorides, total dissolved solids, water absorption, crushing strengths and densities of all the specimens of the brick tiles related to each period.

## 1. Introduction

Brick masonry has been a primary construction material in the historic architecture of the Indian subcontinent due to its availability, durability, and compatibility with lime-based mortars (Feilden, 2003; Torraca, 2009). In Pakistan, brick tiles and fired clay bricks were extensively used in monumental architecture, particularly during the Mughal period, and continued to be employed in later phases for repair and restoration works. The Mughal (1566–1674 A.D.), Sikh (1799–1839 A.D.), British (1846–1927 A.D.), and Post-Independence (1947 to date) periods represent major phases of construction and intervention in Pakistan's architectural heritage. Mughal bricks were typically well-fired and used with lime mortars, resulting in durable masonry systems (Koch, 1991; Asher, 1992). Contrastingly, subsequent repairs in the Sikh and British eras tended to incorporate the use of dissimilar bricks and firing properties, as well as, chemical compositions whereas Post-Independence works tended to use modern materials with minimal assessment of compatibility (Jokilehto, 1999; Feilden, 2003). The Royal Fort of Lahore which is a UNESCO World Heritage site features several phases of construction and restoration of the same buildings and therefore a significant site in terms of material-based study (UNESCO, 2012). The Akbari Gate, Akbari Mahal, and Royal Kitchen are monuments that have brickwork done in all the four historical periods, and this gives a chance to compare the material properties in similar environmental conditions. In architectural conservation, we have to know about the physical and chemical traits of historic bricks before repair or restoration is done. Mismatched bricks can accelerate the degradation process, which can occur through salt crystallization, efflorescence, moisture intrusion, and uneven strength performance (Ashurst and Ashurst, 1988; Torraca, 2009). In

spite of this, there are few systematic comparative studies of bricks produced at various historical periods in the same monument complex in Pakistan. This study addresses this gap by analyzing brick specimens from the Mughal, Sikh, British, and Post-Independence periods collected from selected monuments within the Lahore Fort. Standard laboratory tests—including chemical analysis, water absorption, efflorescence assessment, crushing strengths were conducted to evaluate variations in material properties and assess their implications for conservation practice (ASTM, 2018).

## 2. Materials and Methods

### 2.1 Identification of Brick Tiles Specimens.

The specimens of the Mughal, British and Sikh period brick tiles were determined by the knowledgeable Archaeologists and historians, and the Post-Independence conservation work was determined through the date card engraved on the brick tiles masonry work completed by the Archaeology Department.

### 2.2 Extraction of Specimens & Packing

The material was removed, avoiding to harm the building fabric, through the assistance of the sludge hammer and chisel while encountering with Mughal and British periods masonry work. The brick specimens were taken out from that section of the structures, which was already required the repair/renovation process. The specimens of the brick tiles of Sikh era and Post-Independence era were removed without the use of chisel and hammer. Each of the buildings i.e. Akbari Gate, Akbari Mahal and Royal Kitchen had three brick tiles specimens in each period, i.e., Akbari Gate, Akbari Mahal and Royal Kitchen and were packed carefully in three large zipper polythene bags each. A total of 36 specimens of the brick tiles were gathered as shown, (Figure-1-6).



*Figure 1 & 2: Extraction of Sikh Period Brick Tile Specimens in the Left Figure and Mughal's Period in the Right Figure*



*Figure 3 & 4: Extraction of British Period Brick Tile Specimens in the Left Figure and Post-Independence Period in the Right Figure*

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*Figure 5 & 6: Packing of British Period Brick Tile Specimens in the Left Figure and Transportation of all the Packed Specimens to the Laboratory in the Right One*

### 2.3 Chemical Analysis of Brick Tiles Specimens

The procedure adopted according to the standard B.S 1377 Part-I. The following steps were followed under the supervision of an expert chemist at BRS (Building Research Station), laboratory in chemical section.

#### 2.3.1 Specimens Preparation

First of all, the brick tile specimens were grinded properly and carefully up to fine powder. Care was taken that no important ingredient of the specimens should be wasted.

### 2.3.2 Determination of Sulphates

The laboratory procedure involved the following steps in determining the percentage of sulphates in the powder brick specimens.

- 50-gram specimen powder was added to 100 ml distilled water.
- The solution was stirred by 16 hours or left overnight.
- Thereafter it was filtered using 42 No. filter paper.
- Took 50 ml of the filtrate.
- HCl (20 drops and 2 ml) and distilled water (300 ml) were added.
- Boiled and poured in 10 ml, 5% solution of BaCl<sub>2</sub> drop by drop till the entire amount of ppt was formed at the boiling point.
- Then mixture was left to stand at temperatures below boiling point for 30 minutes.
- Left to cool into room temperature.
- Filtered using 42 No. filter paper.
- Ignited at 800 C ± 50 C for twenty minutes.

Calculated and then weighted.

#### Calculation

Let the weight of residue = a

$$\% \text{ of } \text{SO}_3 = a \times 0.686$$

Specified limit of sulphate in clay for the manufacturing of bricks should be 0.24% maximum.

### 2.3.3 Determination of Chlorides

The steps taken in the laboratory to determine the percentage of chlorides in the powdered brick tiles specimen included the following:

- Sample was 50-gram and mixed in 500 ml distilled water.
- Swirled the suspension and left it overnight and then boiled it 2 hours then cooled down.
- Took 200- ml from the solution.

- Nitric acid (20-ml) was added, heated up, and eventually filtered.
- Silver nitrate solution (5 percent) 3-ml was added.
- Mixed well and boiled.
- Allowed to cool in darkness overnight.
- Weighed the filter paper 42 No. and filtered the solution.
- Heated the filtrate to 100 C to remove the moisture.

#### Calculation

Let the weight of residue = a

$$\% \text{ of Chlorides} = a \times 2.04$$

Generally, the chloride concentrations up to 0.5 percent by weight are regarded as a reason of concern, with more concentrated levels representing a major threat to the quality of the brick.

### 2.3.4 Determination of Total Dissolved Solids

The laboratory procedure to determine the percent of total dissolved solids (TDS) in the specimens of the powder brick tiles used the following steps.

- Weighed 25 mg of specimen and added 100 ml of distilled water and stirred.
- Kept it all night and shook and lastly took reading.

$$\text{Soil ppm} = \text{Reading} \times 4 / 10,000$$

$$\text{Soil ppt} = \text{Reading} \times 4 / 10$$

### 2.4 Dimensional Tolerance

Thirty-six unfractured brick tiles were picked and measured length, width and height, etc. and the values were recorded in the table. The allowances on variations on dimensions are limited to narrow limit ± 3% on class one brick, narrow limit ± 8% on other classes.

### 2.5 Water Absorption of Brick Specimens

The specimen of brick tiles packed in polythene bags labeled with the instructions of physical and mechanical testing were transported to the concrete section laboratory of BRS (Building

Research Station). Each period took three specimens of each building and was tested. The total 36 specimens were permitted to dry in an oven of 105-110 C till they reached a constant weight which normally occurred after 48 hours. Then these samples were left to cool at room temperature (4 to 6 hours with a fan blowing on them). The  $W_1$  of all the specimens was measured in the dry state. After this the specimens were stored in clean water tub at a temperature of  $27 \pm 2$  C, 24 hrs. after which all the specimens were wiped using a damp cloth and weight  $W_2$  was recorded. At last, percentage of water absorption was determined using the formula below.

**Percentage Absorption** =  $[W_2 - W_1] / W_1 \times 100$

#### 2.6 Efflorescence of Brick Specimens

The water absorption of all the brick tiles which had been checked was put in a large dish of tin in a

well-ventilated room at 25 C to 30 C, lying upright. All the tiles were soaked to a depth of 2.5 cm in distilled water. The bricks absorbed the entire water in two days. An equivalent amount of further distilled water was added and another drying period was offered to ensure reliable results. The given clay brick tiles specimens were then be tested on efflorescence.

**Slight:** It was noted that the coverage of not more than 10 percent of the areas of the bricks of the period of Mughal, British Period and Post-Independence period was observed. It implies it was a small efflorescence on these specimens.

**Moderate:** There was a 50 per cent covering of heavy deposits over the brick tiles of the Sikh period. It signifies that it was a moderate efflorescence on these specimens.

*Figure 7&8: Brick Tile Specimens Kept in the Laboratory for Efflorescence Test*



**Crushing Strength of Brick Tile Specimens**

The same specimens of the brick tiles were then subjected to the crushing strength test. Every tile was wiped with cloth to remove the moisture and then the surface faces were covered by gypsum plaster to a depth of 3mm so as to provide the smooth surfaces. Then load was applied at the constant rate of 140 kg/cm<sup>2</sup>/minute until the failure of the specimens occurred as the needle of

the testing machine returned. Lastly, means of the three values obtained on the belongings of three specimen of each period were determined.

**3. Results****3.1 Results of Crushing Strength of Brick Tile Specimens**

The results for the crushing strength of the bricks specimens are given below.

**Table 1 Crushing Strength of Brick Tile Specimens of Akbari Gate**

Description of Specimens	S. No.	Area (inch <sup>2</sup> )	Load (lbs)	Crushing Strength (PSI)	Average Crushing Strength (PSI)
Akbari Gate Mughal's Period	1	30.82	25000	811.16	958.55
	2	30	30000	1000	
	3	31	33000	1064.51	
Akbari Gate Sikh's Period	1	31	15000	483.87	576.47
	2	38	22000	578.9	
	3	34.50	23000	666.66	
Akbari Gate British Period	1	33.0	35000	1060.60	976.76
	2	33.0	32000	969.69	
	3	30	27000	900	
Akbari Gate Post-Independence Period	1	32.0	50000	1562.5	1445.56
	2	31.0	42000	1354.83	
	3	31	44000	1419.35	

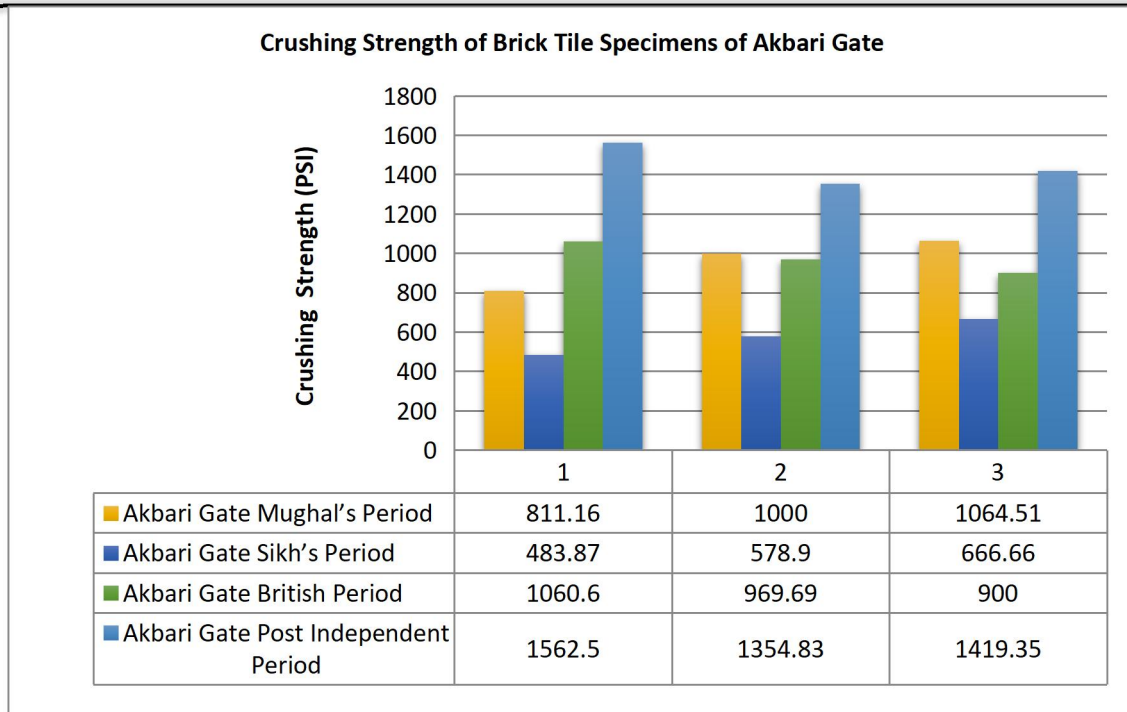


Figure 9: Crushing Strength of Brick Tile Specimens of Akbari Gate

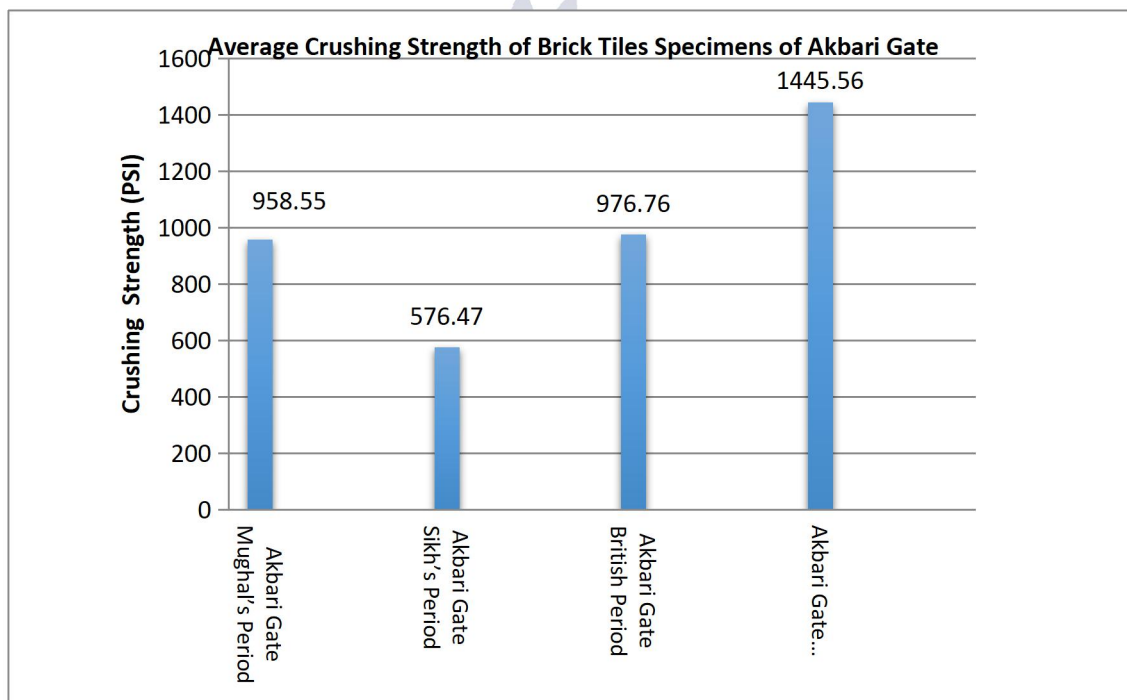


Figure 10: Average Crushing Strength of Brick Tiles Specimens of Akbari Gate

Table 2 Crushing Strength of Brick Tiles Specimens of Akbari Mahal

Description of Sample	S. No.	Area (inch <sup>2</sup> )	Load (lbs)	Crushing Strength (PSI)	Average Crushing Strength (PSI)
Akbari Mahal Mughal's Period	1	40.0	70000	1750	1049.89
	2	38.48	25000	649.68	
	3	40.0	30000	750	
Akbari Mahal Sikh's Period	1	19.6	12000	612.24	999.43
	2	24.44	30000	1227.49	
	3	27.62	32000	1158.58	
Akbari Mahal British Period	1	34.4	25000	726.74	1351.21
	2	26	45000	1730.76	
	3	26	41500	1596.15	
Akbari Mahal Post- Independence Period	1	32	40000	1250	1354.16
	2	32	46000	1437.5	
	3	32	44000	1375	

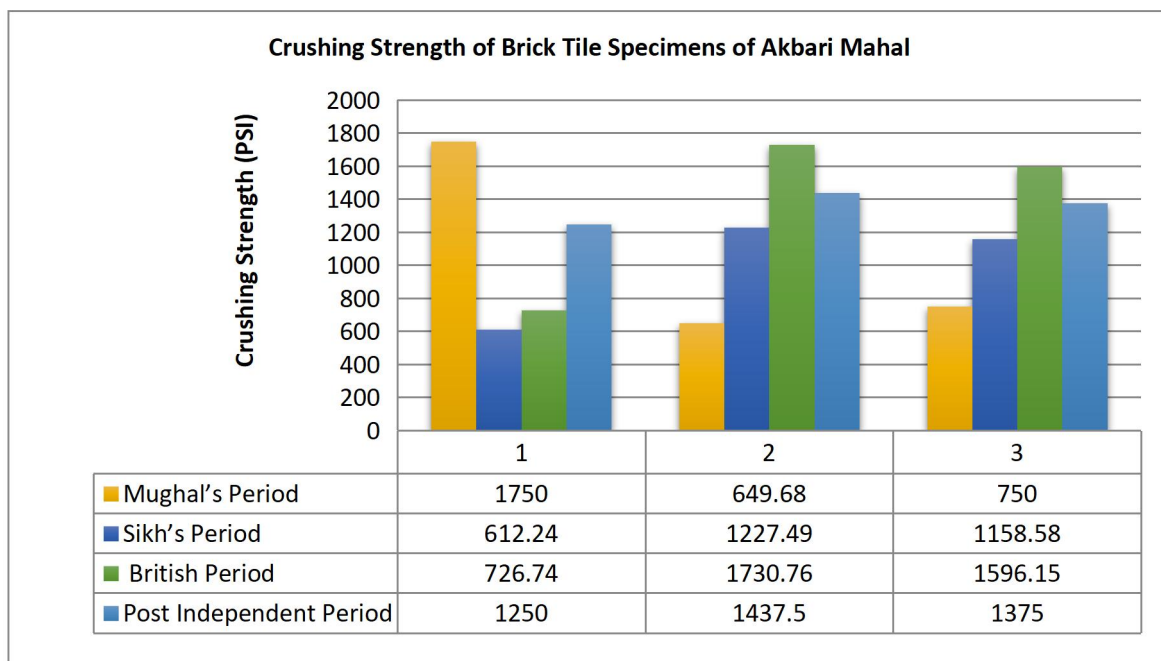


Figure 11: Crushing Strength of Brick Tile Specimens of Akbari Mahal

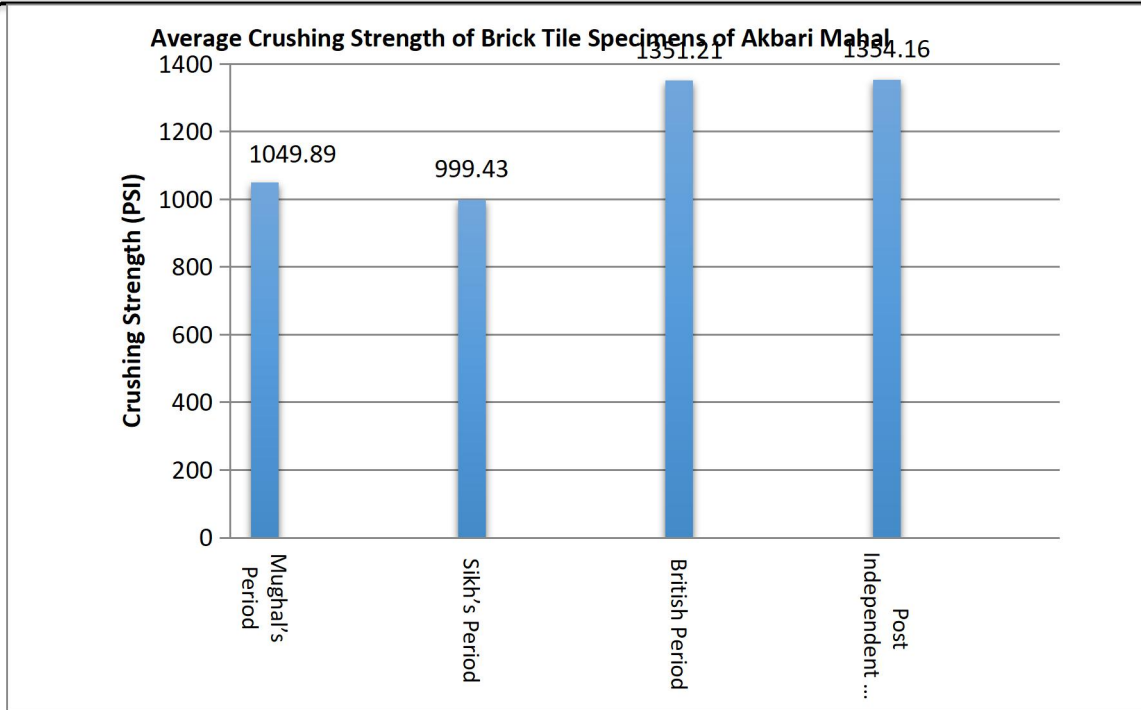


Figure 12: Average Crushing Strength of Brick Tile Specimens of Akbari Mahal

Table 3 Crushing Strength of Brick Tile Specimens of Royal Kitchen

Description of Specimens	S. No.	Area (inch <sup>2</sup> )	Load (lbs)	Crushing Strength (PSI)	Average Crushing Strength (PSI)
Royal Kitchen Mughal's Period	1	35.6	20000	551.79	883.63
	2	30.6	21000	686.27	
	3	34.6	22000	635.83	
Royal Kitchen Sikh's Period	1	27.0	20000	740.74	557.51
	2	26.4	12000	454.54	
	3	26.4	12600	477.27	
Royal Kitchen British Period	1	32	20000	625	941.55
	2	23.5	30000	1276.59	
	3	26	24000	923.07	
Royal Kitchen Post-Independence Period	1	38.7	60000	1550.38	1791.55
	2	38.7	78000	2248.06	
	3	38.7	61000	1576.22	

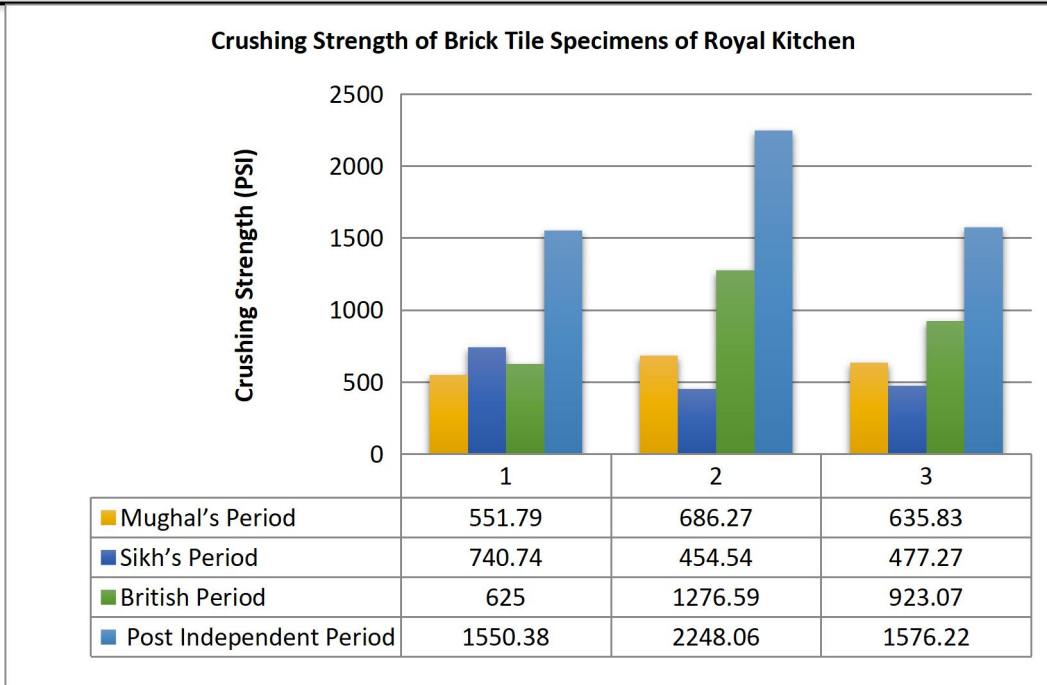


Figure 13: Crushing Strength of Brick Tile Specimens of Royal Kitchen

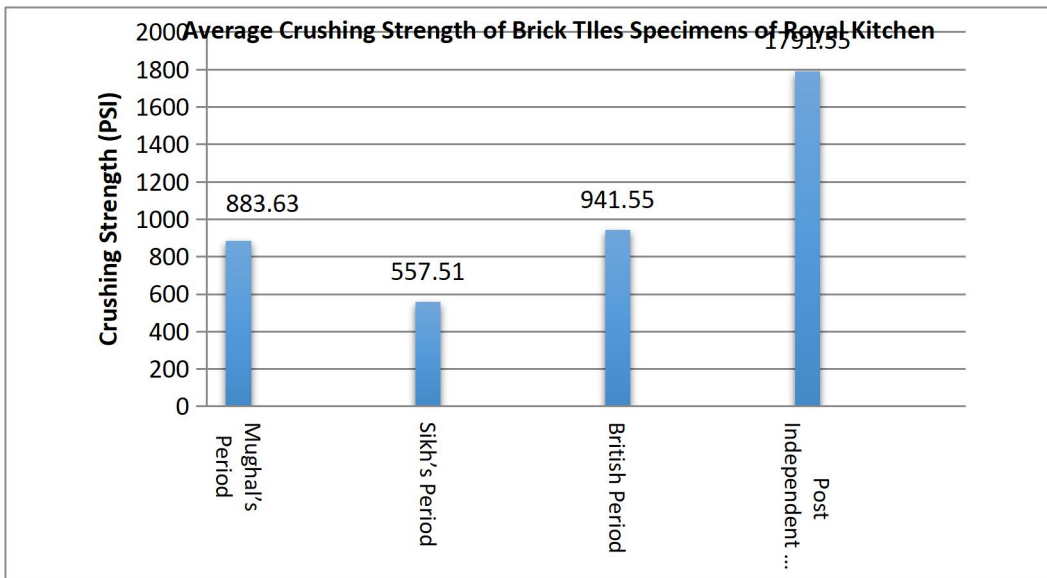


Figure 14: Average Crushing Strength of Brick Tiles Specimens of Royal Kitchen

### 3.2 Results of % Water Absorption of Brick Tile Specimens

The following are the results of the % water absorption of the brick tile specimens.

Table 4: %Water Absorption of Brick Tile Specimens of Akbari Gate

Description of Specimens	S. No.	Dry Weight ( $w_1$ ) (gm)	Wet weight ( $w_2$ ) (gm)	Difference ( $w_2-w_1$ ) (gm)	%Water Absorption ( $(w_2-w_1)/w_1 \times 100$ )	Average % Water Absorption
Akbari Gate Mughal's Period	1	1096	1206	110	10.03	14.91
	2	1012	1160	148	14.62	
	3	1100	1321	221	20.09	
Akbari Gate Sikh's Period	1	1350	1592	242	17.92	17.98
	2	1310	1534	224	17.09	
	3	1320	1570	250	18.93	
Akbari Gate British Period	1	1198	1380	182	15.19	14.16
	2	1592	1726	134	8.41	
	3	1344	1598	254	18.89	
Akbari Gate Post-Independence Period	1	1066	1214	148	13.88	12.11
	2	1245	1412	167	13.41	
	3	1412	1540	128	9.06	

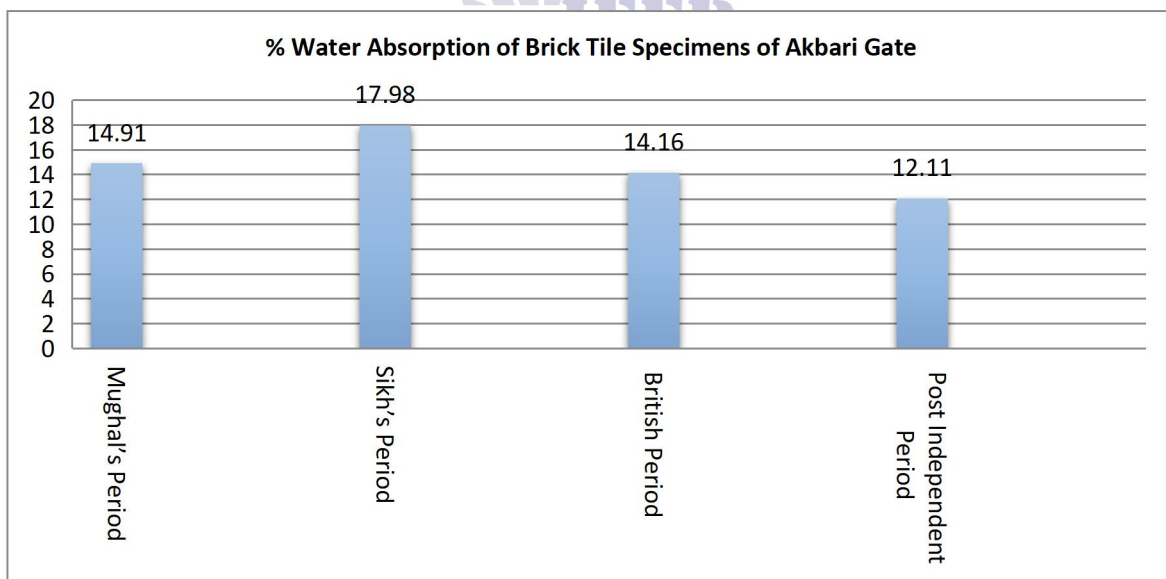


Figure 15: % Water Absorption of Brick Tile Specimens of Akbari Gate

Table 5: %Water Absorption of Brick Tile Specimens of Akbari Mahal

Description of Specimens	S. No.	Dry Weight (w <sub>1</sub> ) (gm)	Wet Weight (w <sub>2</sub> ) (gm)	Difference (w <sub>2</sub> -w <sub>1</sub> ) (gm)	% Water Absorption (w <sub>2</sub> -w <sub>1</sub> )/ w <sub>1</sub> x100	Average % Water Absorption
Akbari Mahal Mughal's Period	1	1785	2015	230	12.88	14.18
	2	1552	1810	258	16.62	
	3	1610	1820	210	13.04	
Akbari Mahal Sikh's Period	1	1100	1280	180	16.36	15.87
	2	1240	1400	160	12.90	
	3	811	960	149	18.37	
Akbari Mahal British Period	1	1398	1588	190	13.59	13.62
	2	956	1068	112	11.71	
	3	956	1105	149	15.58	
Akbari Mahal Post-Independence Period	1	1272	1400	128	10.06	13.33
	2	1076	1198	122	11.33	
	3	1096	1300	204	18.61	

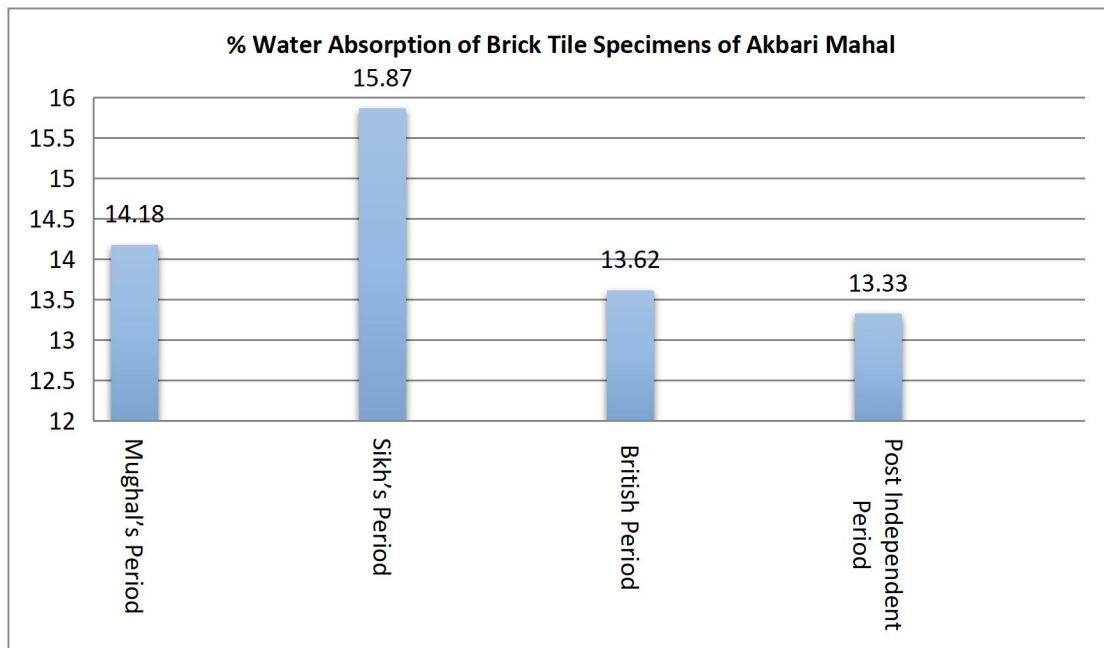


Figure 16: % Water Absorption of Brick Tile Specimens of Akbari Mahal

Table 6: %Water Absorption of Brick Tile Specimens of Royal Kitchen

Description of Specimens	S No.	Dry Weight (w <sub>1</sub> ) (gm)	Wet Weight (w <sub>2</sub> ) (gm)	Difference (w <sub>2</sub> -w <sub>1</sub> ) (gm)	% Water Absorption (w <sub>2</sub> -w <sub>1</sub> )/ w <sub>1</sub> x100	Average % Water Absorption
Royal Kitchen	1	1626	1878	252	15.49	16.13
	2	1192	1380	188	15.77	

Mughal's Period	3	1306	1530	224	17.15	
Royal Kitchen	1	1203	1410	207	17.20	17.0
Sikh's Period	2	1356	1536	180	13.27	
	3	1169	1409	240	20.53	
Royal Kitchen	1	1340	1530	190	14.17	14.60
British Period	2	1230	1404	174	14.14	
	3	1290	1490	200	15.50	
Royal Kitchen	1	1846	2110	264	14.30	14.43
Post-Independence Period	2	1790	2030	240	13.40	
	3	1790	2070	280	15.64	

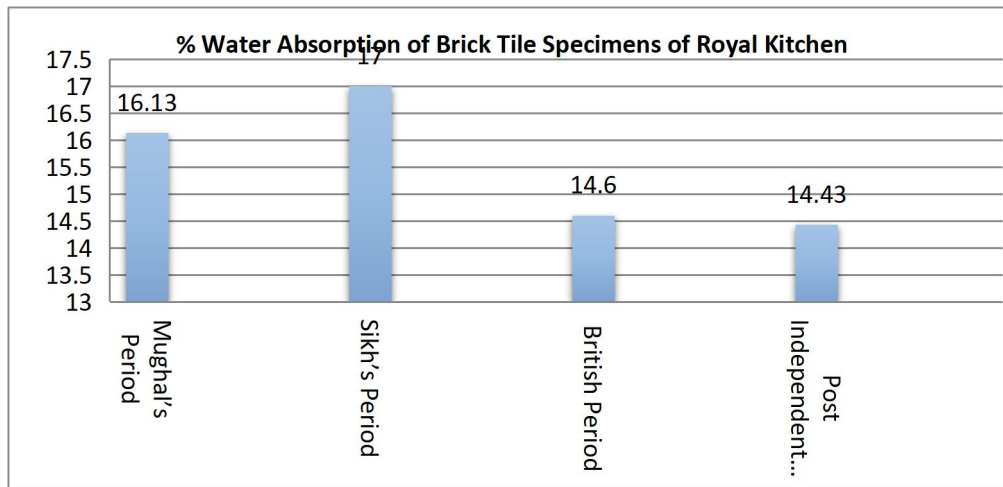


Figure-17: % Water Absorption of Brick Tile Specimens of Royal Kitchen

3.3 Results of Densities of Brick Tile Specimens

The following are the results of the densities of brick Tile specimens.

Table-7: Densities of Brick Tile Specimens of Akbari Gate

Description of Specimens	S. No.	Weight (gm)	Area (inch <sup>2</sup> )	Volume (inch <sup>3</sup> )	Density (g/inch <sup>3</sup> )	Average Density (g/inch <sup>3</sup> )
Akbari Gate Mughal's Period	1	1096	30.82	46.23	23.70	23.27
	2	1012	30	45.00	22.48	
	3	1100	31	46.5	23.65	
Akbari Gate Sikh's Period	1	1350	31	46.5	29.03	25.83
	2	1310	38	57	22.98	
	3	1320	34.50	51.75	25.50	
Akbari Gate British Period	1	1198	33.0	49.5	24.20	28.74
	2	1592	33.0	49.5	32.16	

Period	3	1344	30	45	29.86	
Akbari Gate Post-Independence Period	1	1066	32.0	48	22.20	26.44
	2	1245	31.0	46.5	26.77	
	3	1412	31.0	46.5	30.36	

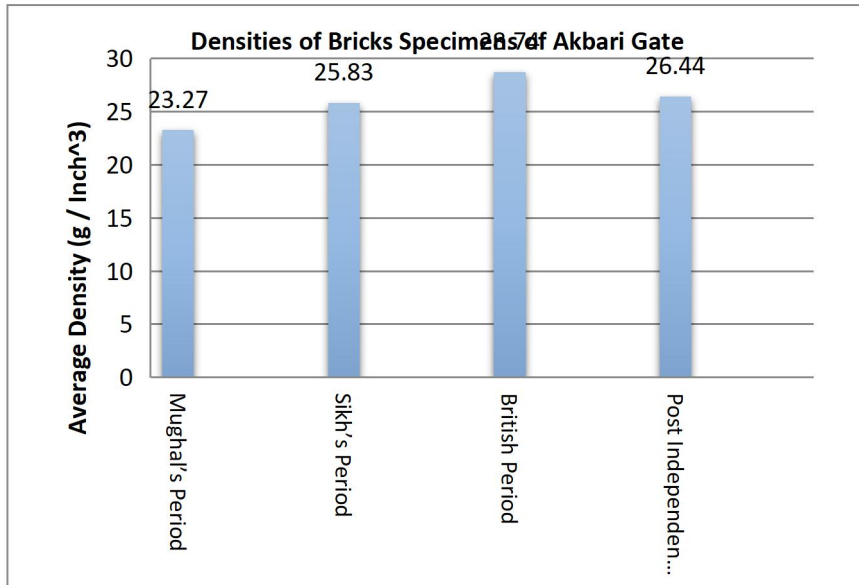


Figure-14: Densities of Brick Tile Specimens of Akbari Gate

Table 8: Densities of Brick Tile Specimens of Akbari Mahal

Description of Specimens	S. No.	Weight (gm)	Area (inch <sup>2</sup> )	Volume (inch <sup>3</sup> )	Density (g/inch <sup>3</sup> )	Average Density (g/inch <sup>3</sup> )
Akbari Mahal	1	1785	40.0	60	29.75	27.82
Mughal's Period	2	1552	38.48	57.72	26.88	
	3	1610	40.0	60	26.83	
Akbari Mahal	1	1100	19.6	29.4	37.41	30.26
Sikh's Period	2	1240	24.44	36.66	33.82	
	3	811	27.62	41.43	19.57	
Akbari Mahal	1	1398	34.4	51.6	27.09	25.37
British Period	2	956	26	39	24.51	
	3	956	26	39	24.51	
Akbari Mahal	1	1272	32	48	26.5	23.91
Post-Independence Period	2	1076	32	48	22.41	
	3	1096	32	48	22.83	

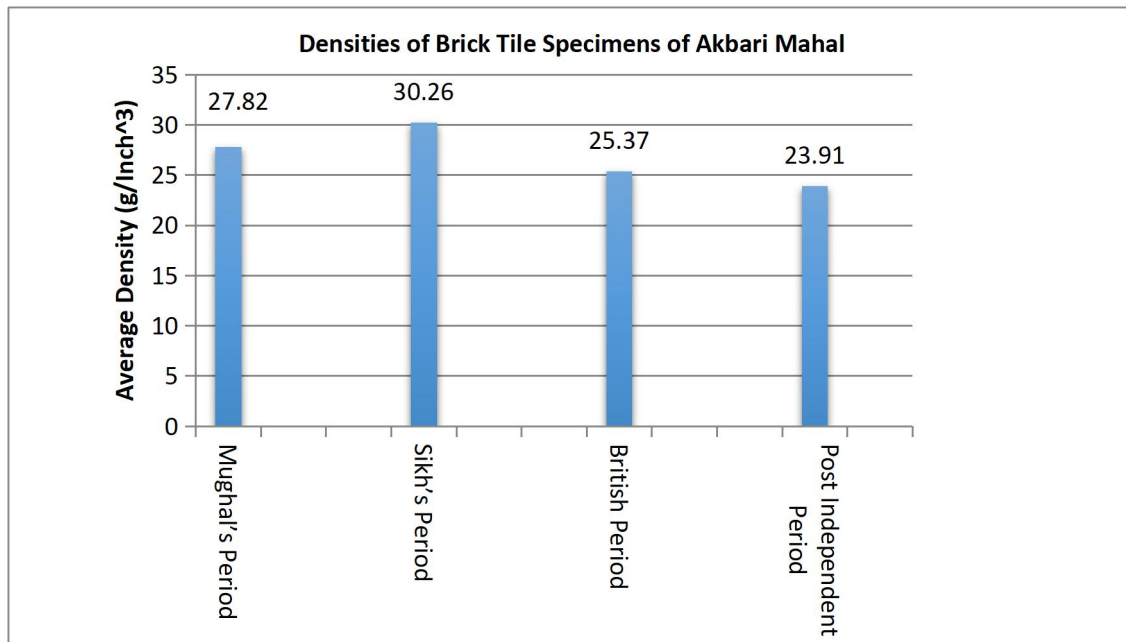


Figure 19: Densities of Brick Tile Specimens of Akbari Mahal

Table 9: Densities of Brick Tile Specimens of Royal Kitchen

Description of Specimens	S. No.	Weight (gm)	Area (inch <sup>2</sup> )	Volume (inch <sup>3</sup> )	Density (g/inch <sup>3</sup> )	Average Density (g/inch <sup>3</sup> )
Royal Kitchen	1	1626	35.6	53.4	30.44	27.18
Mughal's Period	2	1192	30.6	45.9	25.96	
	3	1306	34.6	51.9	25.16	
Royal Kitchen	1	1203	27.0	40.5	29.70	26.43
Sikh's Period	2	1356	26.4	39.6	34.24	
	3	1169	26.4	39.6	29.52	
Royal Kitchen	1	1340	32	48	27.91	31.95
British Period	2	1230	23.5	35.25	34.89	
	3	1290	26	39	33.07	
Royal Kitchen	1	1846	38.7	58.05	31.80	31.15
Post-Independence	2	1790	38.7	58.05	30.83	
Period	3	1790	38.7	58.05	30.83	

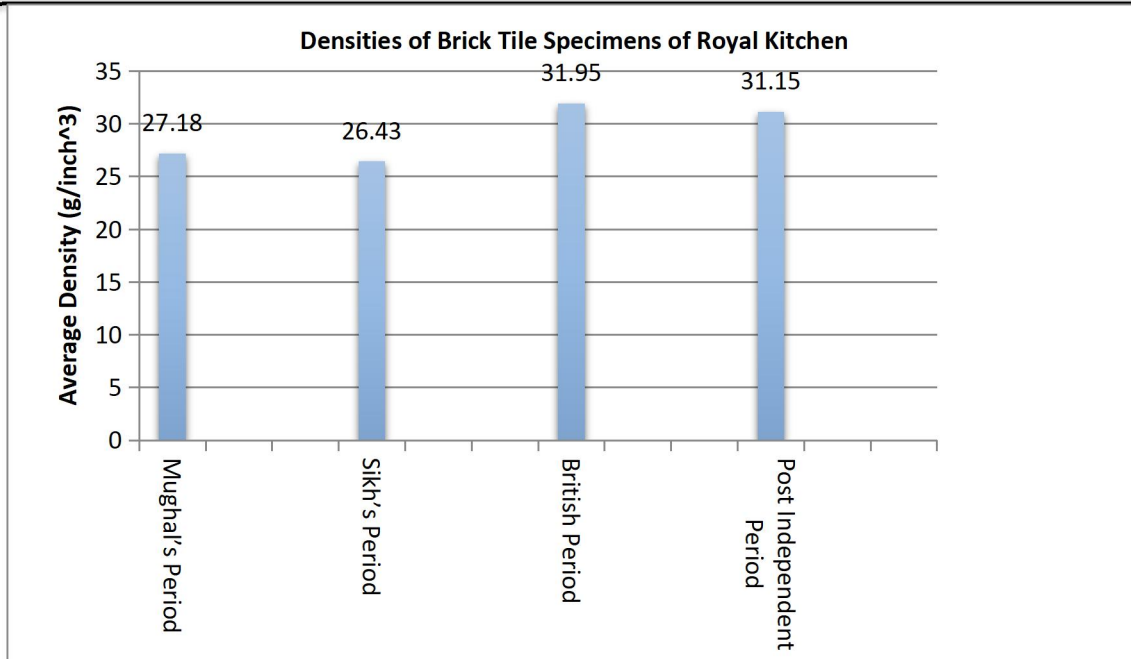


Figure 20: Densities of Brick Tile Specimens of Royal Kitchen

3.4 Results of Chemical Analysis of Brick Tile Specimens

The following are the results of the chemical analysis of brick tile specimens.

Table 10: Chemical Analysis of Brick Tile Specimens of Akbari Gate

Description of Specimens	S. No.	%Total Solids	Dissolved	% Total Sulphates	%Total Chlorides
Akbari Gate Mughal's Period	1	1.24		0.13	0.40
Akbari Gate Sikh's Period	2	6.27		2.46	3.21
Akbari Gate British Period	3	2.24		0.35	0.48
Akbari Gate Post-Independence Period	4	1.00		0.25	0.53

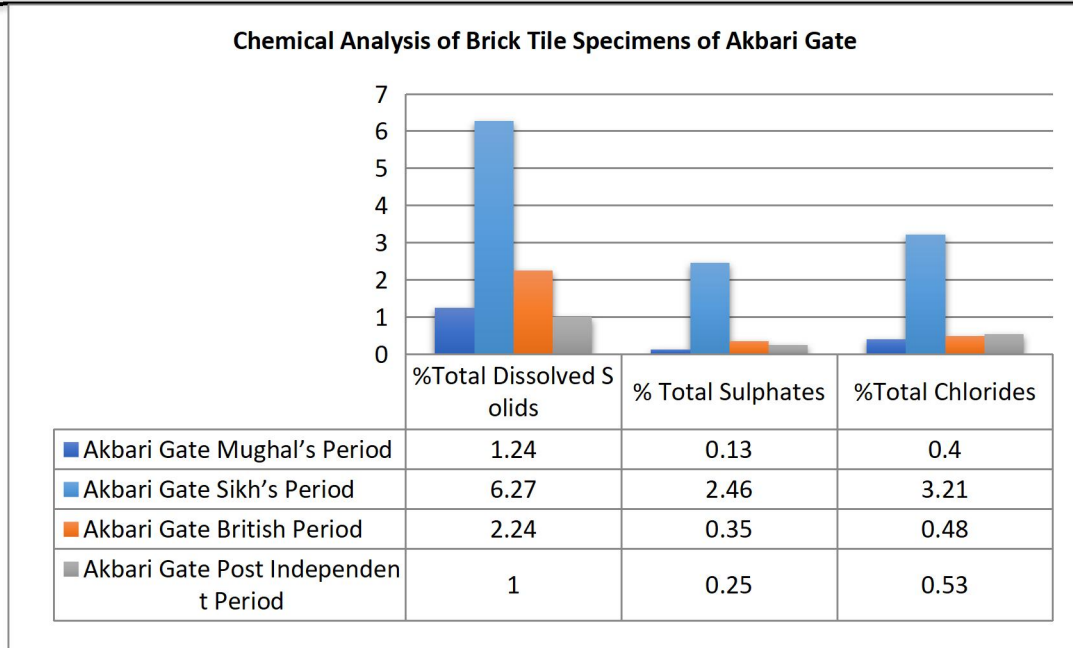


Figure 21: Chemical Analysis of Brick Tile Specimens of Akbari Gate

Table 11: Chemical Analysis of Brick Tile Specimens of Akbari Mahal

Description of Specimens	S. No.	%Total Dissolved Solids	%Total Sulphates	%Total Chlorides
Akbari Mahal Mughal's Period	1	2.00	1.76	2.65
Akbari Mahal Sikh's Period	2	4.29	1.11	2.21
Akbari Mahal British Period	3	0.56	Traces	0.04
Akbari Mahal Post-Independence Period	4	1.39	0.38	0.83

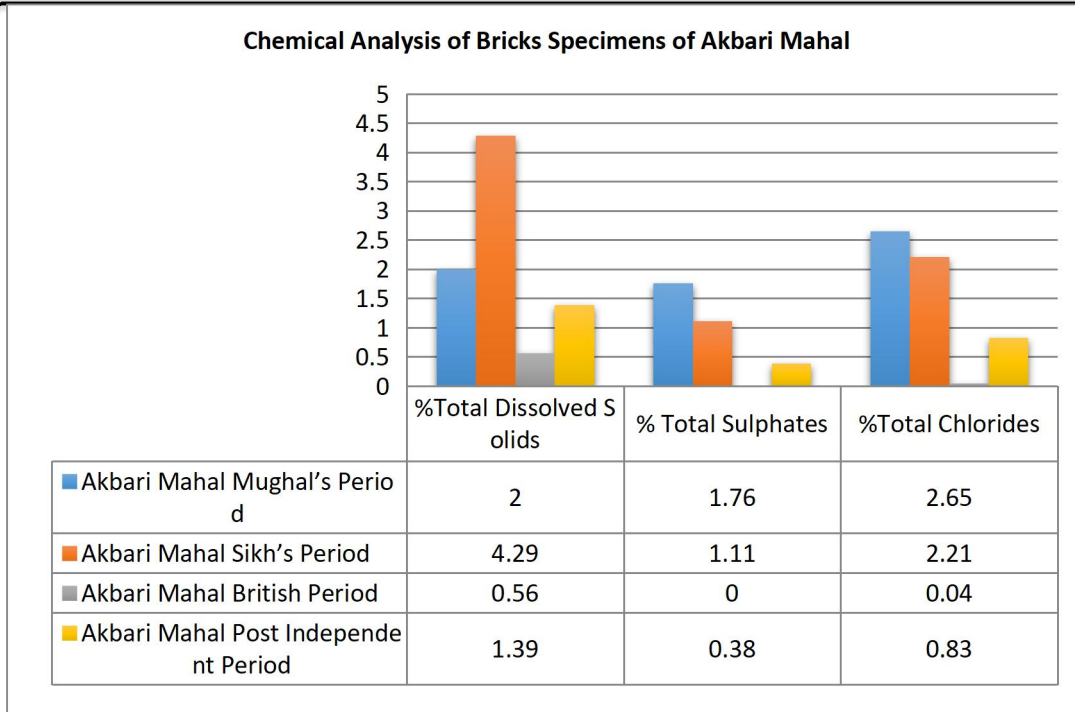
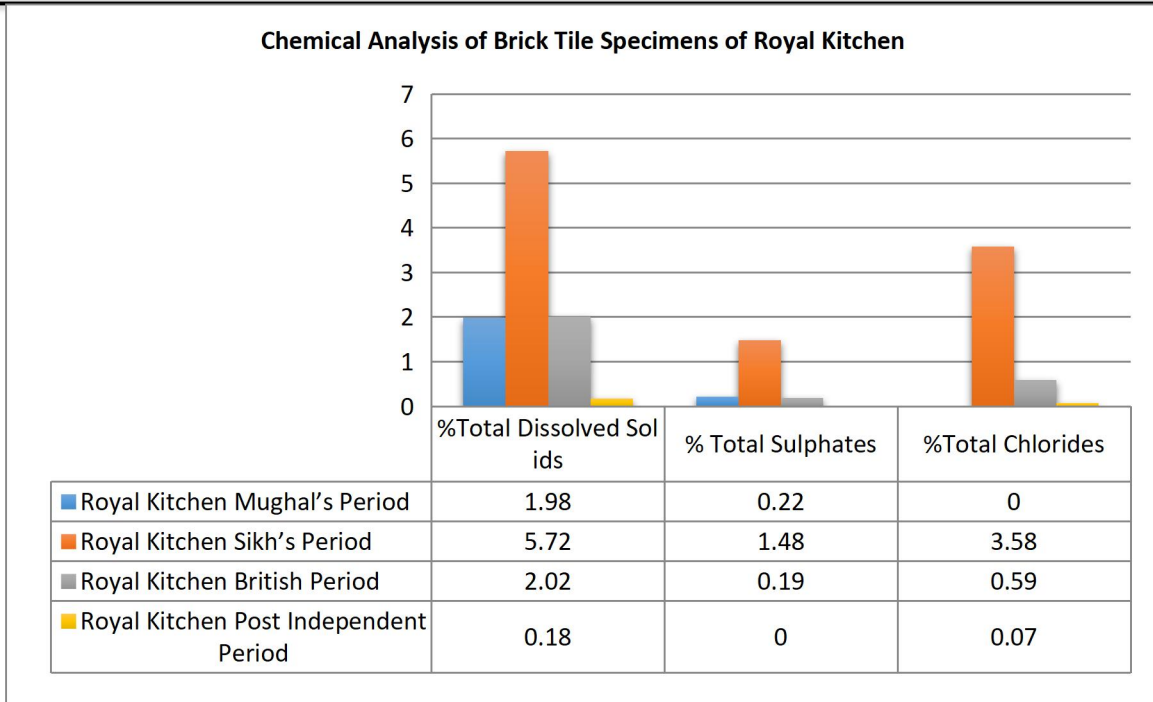


Figure 22: Chemical Analysis of Brick Tile Specimens of Akbari Mahal

Table 12: Chemical Analysis of Brick Tile Specimens of Royal Kitchen

Description of Sample	S. No.	%Total Dissolved Solids	% Total Sulphates	%Total Chlorides
Royal Kitchen Mughal's Period	1	1.98	0.22	0.67
Royal Kitchen Sikh's Period	2	5.72	1.48	3.58
Royal Kitchen British Period	3	2.02	0.19	0.59
Royal Kitchen Post Independence Period	4	0.18	Traces	0.07



*Figure 23: Chemical Analysis of Brick Tile Specimens of Royal Kitchen*

**4. Discussion**

The total dissolved solids (TDS), sulphates, and chlorides are comparatively high in the brick tiles from the Sikh period. This indicates that the clay selected for brick manufacturing during the Sikh period contained a high concentration of sulphates and that no systematic testing or assessment of clay properties was carried out prior to brick tile production. Although Mughal period brick tiles collected from Akbari Gate also exhibit elevated chloride content, the bricks from the Sikh period show exceptionally high chloride levels exceeding 3% which is far above the generally accepted maximum limit of 0.2% for chlorides in masonry materials (ASTM C67, 2023; Neville, 2011).

Aging is one of the contributing factors to increased chloride content, as chlorides penetrate masonry through prolonged exposure to rainwater and floodwater. As Mughal brick tiles are about 450 years old, Sikh bricks are about 250 years old, and British-period bricks are almost 100 years old, their years of exposure to hostile environmental

factors have led to salt intrusion over the years (ICOMOS, 2004; Torraca, 2009). Yet, the much greater chloride in Sikh-period bricks indicates that the deterioration cannot be simply attributed to the environmental exposure only. The level of Sulphate normally reduces as the bricks are fired at high temperatures of over 1000 C. The presence of high sulphate in Sikh-period brick tiles hence points out that there was improper firing of bricks and under-fired bricks were used to build structures. Poor firing does not only leave the sulphates, but also makes the bricks porous (Cultrone et al., 2005). This enhanced porosity, which led to more absorption of moisture thereby enabling chlorides to get into and settle in the brick skeleton. Further indication of this interpretation comes on water absorption. The Mughal time bricks have been shown to have a value of water absorption that is slightly above the normal ranges of water absorption, whereas Sikh period bricks have a very poor performance. Sikh bricks have an average water absorption of about

17 per cent, which is more than the allowable limit even by the second-grade bricks defined in standard masonry specifications (ASTM C67, 2023; IS 3495, 2017). High water absorption will verify the highly porous character of such bricks and is strongly associated with the high levels of sulphate and chloride. Large porosity increases the deterioration process of bricks by taking in large amounts of water. When the evaporation takes place, the dissolved salts crystallize inside the pore structure, creating internal stresses that give rise to micro-cracking, scaling up of the surfaces and subsequent disintegration of the bricks (Neville, 2011; Torraca, 2009). These salts also seep to the surface of the bricks leaving visible efflorescence. It was noted that, Sikh period bricks were under moderate salt attack as compared to bricks in other periods which tended to exhibit slight efflorescence only. As a result, the crushing strength of the Sikh period bricks is very low relative to the Mughal and British period bricks. The findings show that the percentage of water absorption is directly proportional to the quantity of soluble salts and crushing strength is inversely proportional to the salt content and the water absorption. In general, the research indicates that there is not only a significant difference in the strength of bricks between the Pre-Post-Independence eras but also the considerable discrepancies in the bricks manufactured during the Post-Independence era. Even with the modern technology and the established standards of testing in the present day, there is still a considerable range of difference in the new bricks applied in the Archaeology Department. These bricks have crushing strengths between 2248 PSI to up to 1250 PSI, which shows that there was no great control in the quality of the bricks when they were made and when they were purchased (ASTM C67, 2023). Moreover, although Mughal, Sikh, and the British bricks are slightly

uniform in size and weight, the presently used bricks in conservation projects are marked with a lot of incompetence. As an illustration, the area of bricks employed in the Royal Kitchen is about 39 square inches, the average of bricks in Akbari Gate and Akbari Mahal is about 32 square inches. These sizes are not compatible with the historic brick sizes employed in the Mughal, Sikh or British era, and the differences in the weight of the bricks also contribute to incompatibility problems. This lack of material compatibility, authenticity and durability of heritage buildings in the long-term (ICOMOS, 2004; Venice Charter, 1964).

### 5. Conclusion & Recommendations

The study concludes that the visible differences in the size, quality and performance of the brick tiles produced in the different historical eras can be largely explained by the lack of standardized manufacturing processes, insufficiency of technological capacity, and ineffective project management systems prior to the Post-Independence era. Nevertheless, even with the existence of better technology in the contemporary world, the identical problems still exist, as the brick tiles that are utilized in the conservation projects are not always in accordance with the prescribed standards.

The research study indicates that most of the brick tiles incorporated in contemporary conservation projects are either small or too big and do not correspond to the standard testing and quality measures. This means that even the manufacturers of bricks are not always subject to standardized moulding processes and also that the properties of clay are not being analyzed properly before the bricks are manufactured. These non-standardized bricks also bring about incompatibility when used in historic masonry and cause structural distress, accelerated decay and decrease in lifespan of heritage buildings. The paper also points out that

the relative percentage and thickness of masonry unit to mortar joints varied with time. In subsequent historical eras, the decreased thickness of masonry joints and non-conformity of the dimensions of the bricks are not in agreement with the established conservation ethics, which is presented in sources like the ICOMOS guidelines and the Venice Charter. Such practices undermine material authenticity and structural compatibility in heritage conservation.

It is highly suggested based on these findings that the Archaeology Department and the concerned conservation authorities should have a detailed Work Breakdown Structure (WBS) in place before attempting any such future conservation project. Within this context, the historical investigation of historic bricks, their dimensions, physical properties, strength, and composition of clay, etc. should be conducted in relation to each historical period. This assessment can be critical to the engineers and material specialists. In conservation projects, bricks must be supplied with well-known and standardized kilns where the quality control is being implemented during all the stages of manufacturing, starting with the selection of clay, to the final firing. The quality of bricks has to be tested using the standard testing procedures that are reproduced in the literature and can be applied in this analysis such as dimensional accuracy test, crushing strength test, and physical performance tests.

The implementation of a structured WBS and strict quality control in brick procurement will significantly reduce the need for repetitive conservation interventions. In the long term, this approach will lower rework costs, improve workmanship quality, and enhance the structural integrity, authenticity, and lifespan of heritage buildings.

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