Journal of Nepal Geological Society, 2023, Vol. 65 (Sp. Issue), pp. 141–150
https://doi.org/10.3126/jngs.v65i01.57773

Quality assessment of bricks produced in Chitwan District, central Nepal

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ABSTRACT

Based on the physical, mechanical, and mineralogical properties of fire clay bricks from different brick industries of the Chitwan District, the quality of bricks was determined. The specific objective of this study was to assess the characteristics and comparison of bricks produced from different kilns. Both desk study and field study was carried out for this purpose. Parameters such as dimension, hardness, soundness, and impact were studied in the field for twenty brick samples obtained from each brick industry. Water absorption, apparent porosity, bulk density, and compressive strength tests were carried out in the laboratory, encompassing high and low quality of samples. Additionally, seven types of bricks were manually crafted using clay from those industries. For mineralogical analysis, XRD was carried out on seven brick samples each from seven different brick industries. IS standard was followed for various testing. The dimension test results showed that none of the samples meet the standard. Similarly, the laboratory test result showed that the bulk density of each brick sample increased with increasing compressive strength and decreasing water absorption capacity and apparent porosity. XRD analysis has identified mineral phases like quartz, hematite, and berlinite. Thus, this research tries to provide valuable insights into brick quality, strength and potential applications..

Keywords: Clay bricks, compressive strength, water absorption, bulk density, XRD

Received: 24 March 2023 **Accepted:** 28 June 2023

INTRODUCTION

Bricks are the most important artificial construction materials and have been used globally for many years. Although sun-dried bricks and fired clay bricks are popular from the beginning of human civilization about 10,000 years ago (Lourenco et al., 2010), the low strength and durability of the former increased the wider and global utilization of the fired clay bricks. Recent fire bricks are newly produced bricks and are more durable with high resistance and strength in harsh climatic conditions (Kornmann, 1986). In Nepal, bricks have been used as construction materials and their demand is increasing due to fast-growing urbanization and engineering infrastructure development.

Each year, more than 1.5 trillion bricks are made worldwide. Among these, 1.35 billion bricks originate in Asia, with Nepal contributing 1.81% of the total (Nepal et al., 2019). The manufacturing rate of bricks in Nepal has been increasing by 87.5% between 2009 and 2012 (Manandhar and Dangol, 2013; Nepal et al., 2019). After the 2015 devastating Gorkha Earthquake, the demand and manufacture of bricks are increasing more drastically. Due to the increasing demand for bricks, the production is more focused on quantity rather than quality and hence it is necessary to investigate the quality of fire clay bricks before their use in infrastructure. Brick quality depends on the raw materials used during its manufacturing stage, firing temperature (Elert et al., 2003; Cultrone et al., 2004; Kazmi et al., 2016), human factors (Azam et al., 2022), brick kilns, firing time, and overall processes (Subedi, 2020). Both clay and fine sand are the most important raw materials that are used for brick. If the soil is of poor quality and contains a lot of clay with plasticity, cracks will form. The production process, such as the high clay content, uneven drying, and burning of the bricks, can also result in cracks developing in burnt brick (Danso and Akwaboah, 2021). The first step in reducing the occurrence of cracks is to boost the clay's strength. Clay possesses a plasticity behavior and in order to improve its strength, sand is added to clay in the proportion of 30–70% sand and clay (Weaver, 1997; Vekey, 1998). Also, adding fibers that act as reinforcement and minimize cracking can help to improve quality of clay (Ekinci and Ferreira, 2012). In the case of Nepal, such an addition of fibers is not yet practiced.

In Nepal, bricks are produced from 1294 legally functioning brick kilns (Shrestha and Thygerson, 2019) and are used for various construction activities. Each brick manufacturing industry has its own manufacturing processes. This process leads to the production of bricks of different quality. A large number of physical and mechanical properties help to assess the strength and quality of bricks which in turn determine the characteristics of bricks. Brick kilns and firing temperature are important factors to be considered during brick production for their quality determination. The water absorption capacity and compressive strength vary greatly as per the type of kiln used and the position of bricks inside the kiln during the firing process (Laefer et al., 2004; Subedi, 2020). Also, the compressive strength increased and water absorption capacity decreased with an increase in firing temperature (Karaman et al., 2006; Tsega et al., 2017). Clay bricks' compressive strength increases slightly with increased fire time while their ability to absorb water decreases (Tsega et al., 2017). However, Karaman et al. (2006) observed no significant difference. The strength and durability of bricks depend on their physical and mechanical properties. Water absorption capacity, bulk density, and apparent porosity are the physical properties responsible for brick strength, whereas compressive strength determines the mechanical properties of bricks. The determination of the quality of bricks and their testing is lacking in Nepal. Therefore, the measurement of sustainability and the life duration of infrastructure cannot be determined since quality determination is lagging. In this study, numerous physical and mechanical tests were carried out in the field and laboratory, and various standard codes were followed in order to determine the quality of bricks, allowing their usage for a variety of development projects and lowering the risk of infrastructure collapse.

METHODOLOGY

Twenty brick samples from seven different brick manufacturing industries named J, O, S, A, B, M, and D running in the Chitwan District were used in order to carry out the research work in the field. These brick manufacturing industries cover the eastern part of the district (Fig. 1). Bricks samples for field tests are of various grades that are sampled randomly from the pile of the grade of bricks. Some selected samples of bricks were used for laboratory tests.

In order to assess the objective of this research paper, a large number of physical, mechanical, and mineralogical properties of the brick sample were determined. Desk research, field research, and laboratory research were all done to ascertain the aforementioned characteristics. The research study's approach is best described by the flowchart (Fig. 2). The field visit starts with the brick manufacturing process, followed by a field test, and ends with sampling collection for laboratory tests. The brick manufacturing process is initiated with the pugging of raw materials, moulding, drying and stacking, and ends with the firing process (Fig. 3). Pugging guaranteed the homogeneity of soil with different additives. Prior to pugging, effort should be taken to thoroughly eliminate all extraneous objects. If the extraneous objects were not removed before pugging, it would be difficult to mould the soil into bricks and the final product would be of low quality. Manual and mechanized pugging was followed for this purpose. Moulding is a second stage where a shape was provided to the clay. For this, each brick manufacturing industry has its own rectangular mould box having its own mark as an identification. The ground was properly labeled and cleaned before molding. The area was watered the day before the soil begin to mould. To prevent freshly laid bricks from sticking to the mould box and ground, releasing agent (fine sand) was sprayed on mould box and on the surface before moulding. The green bricks were carefully removed from the mould box after moulding. Then the drying phase was initiated. The drying process was conducted such that uniform drying of brick samples are recorded. The plasticity of soil and its grain size has a vital role for determining the time of drying. Bricks having large pores dry faster as compared to the bricks with clayey soil because

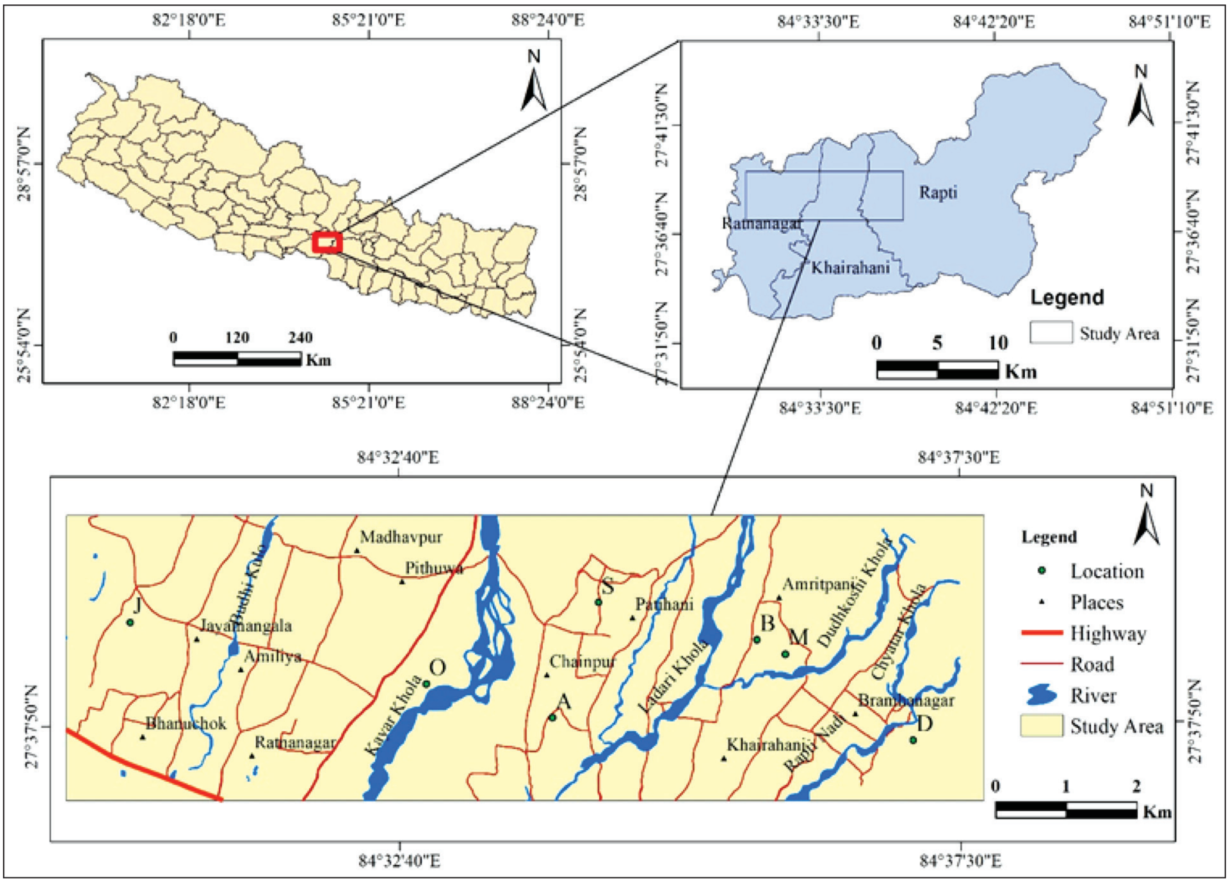

Fig. 1: Map of the study area showing locations of brick manufacturing industries.

of capillary action (Mueller et al., 2008). After drying for a required time period, bricks are fired at the brick kiln at about 550°C to 1100°C. A total of 28 days was required for complete firing under normal conditions. Similarly, the position of bricks during the firing process describe the grade of the bricks. The laboratory and field testing values were used to assess the physical, mechanical and mineralogical properties.

Physical and mechanical analysis

For the physical analysis of the brick samples, a number of physical tests, including those for dimension, hardness, soundness, impact, water absorption, apparent porosity, and bulk density, were conducted. To determine the physical qualities in the field, 20 brick samples from each brick manufacturing industry were sampled. Each brick sample's dimensions were measured using an mm scale for the dimension test. For this, the NBC (109-1994) standard was used. Each sample was scratched with a different brick sample to determine its hardness. For the soundness test, two brick samples were struck together so as to ascertain whether they produce metallic or non-metallic sound. While knocking two brick samples, if it produces metallic sound, it was considered to be a good quality brick. For the impact test, a brick sample was permitted to fall from a height of 1 m into normal ground conditions.

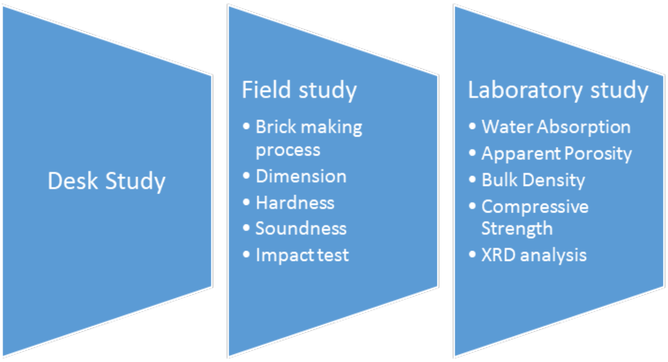

Fig. 2: Flowchart of methodology used in research study.

The physical characteristics of the brick samples are also determined using IS standards. For the bulk density test, the dry weight of brick samples is weighed after drying them in the heating oven at a temperature of about 105°C to 110°C. The IS 875 (Part 1) – 1987 was followed to calculate the volume.

The water absorption test was carried out by using the IS 3495 (Part 2): 1992 standard. The test specimen was dried at 105°C to 110°C in the heating oven till it maintains a constant weight. The specimen was then cooled to room temperature and weighed as dry weight (M1). The brick sample was then immersed in water for 24 hrs. After 24 hrs, the brick sample was removed from the water. The specimen was then wiped out using a cotton cloth. The saturated weight of the brick specimen was calculated as (M2). The relations are developed from the equations 1–3.

Mechanical properties: The mechanical properties of the brick sample are determined using a compressive strength test.

Fig. 3: Field observation of brick manufacturing sites; (a) manual pugging, (b) mechanized pugging, (c) moulding, (d) drying and stacking.

Smart Drilling & Testing Pvt. Ltd. measured the compressive strength test using an automatic compression testing machine from Enkay Enterprises (Fig. 4). IS 3495 (Part 1): 1992 was followed for this test. The unevenness of the brick sample was removed using sharp objects. After this, the brick samples were immersed in the water for 24 hrs. The frogs or voids of each brick sample were filled with mortar (1:3 cement mortar). After 24 hrs, the dimensions of each brick sample that can be measured with the machine were measured. These measurements were then used in Enkay software (Fig. 4) and the maximum load causing failure was noted (Eq. 4).

$$\text{Bulk density} = \frac{\text{Dry weight of the brick}}{\text{Volume of the brick}} \tag{1}$$

$$\text{Water absorption (\%)} = \frac{\text{(Saturated weight of the brick (M2)-Dry weight of the brick (M1))}}{\text{Dry weight of the brick(M1)}} \times 100 \tag{2}$$

$$\text{Apparent porosity (\%)} = \frac{\text{(Saturated weight of the brick-Dry weight of the brick)}}{\text{Volume of the brick}} \times 100 \tag{3}$$

$$\text{Compressive strength (N/mm}^2\text{) (kgf/cm}^2\text{)} = \frac{\text{Maximum load at failure in N (kgf)}}{\text{Average area of bed faces in mm}^2\text{(cm}^2\text{)}} \tag{4}$$

Mineralogical studies

It is crucial to identify the sort of clay minerals present before making bricks. Bricks will break, expand, and crack during the brick-making process if the clay has a higher proportion of expansive clay minerals. Hence, it is important to conduct a mineralogical analysis of clay minerals. Also, a mineralogical study of burnt clay bricks was carried out to evaluate the firing temperature and its quality. The temperature during their production is determined by the presence of phase minerals. Mineralogical analysis can be carried out using XRD and FTIR analysis. For this study, only XRD was carried out for the mineralogical analysis of bricks.

X–Ray diffraction is a powder diffraction method for the identification of mineral species. XRD of seven brick samples named J, O, S, A, B, M, and D was carried out with CuKά radiation° in the laboratory of Nepal Academy of Science and Technology (NAST) Khumaltar, Lalitpur. Brick was first crushed into fine powder form using a hammer. A sieve analysis of crushed brick was performed using ASTM D422-63. Very fine samples retained on the pan were used for this purpose. Since XRD was done for the identification of clay and non-clay minerals, bulk samples were used.

RESULTS AND DISCUSSION

Physical and mechanical properties

The physical and mechanical analysis of brick samples was based on field and laboratory test results of different physical parameters. These parameters are the prime important factors for determining the brick quality in any part of the world. A large number of physical tests: dimension, hardness, impact, soundness, bulk density, water absorption, and apparent porosity, and mechanical test provide the basic information regarding the quality and strength of the bricks.

Field and laboratory testing results

Twenty brick samples from each brick manufacturing industry were sampled, and dimensions were measured. According to Nepal's national building code (NBC 109 - 1994), bricks must have the following dimensions: 240 mm x 115 mm x 57 mm. Similar to this, bricks must have dimensions of 190 mm x 90 mm x 90 mm or 190 mm x 90 mm x 40 mm in accordance with IS 1077: 1992. None of the 20 samples from each brick production sector follows the standard (Table 1). Figure 5 depicts the results of the hardness, soundness, and impact tests performed on the 20 brick samples from each brick manufacturing industry. The hardness test results showed that 20 brick samples from each brick industry have different hardness depending upon their manufacturing process, firing temperature, exposure to water and sunlight, and the selected samples' quality. The test results revealed that the 'D' industry's chosen brick samples are substantially harder than those from any other brick industry. Additionally, for seven brick industries, the range of broken brick samples is 4 to 11.

For the purpose of evaluating the strength of bricks from various brick-producing industries, numerous laboratory tests have been carried out. Along with mechanical qualities, bulk density, water absorption capacity, and apparent porosity, all play a significant role. The density and standard brick sizes vary from country to country depending on the brick's measurements. According to IS 875 (Part 1) - 1987, bricks should typically have a density of between 1600.00 kg/m^3 and 1920.00 kg/m^3. The test findings revealed that for brick samples from seven brick manufacturers, the bulk density ranges from 1654.453 kg/m^3 to 1949.666 kg/m^3 (1.65 to 1.949 gm/cm^3) (Fig. 6). Likewise, the bulk density of hand specimens ranges from 2015.721121 to 2449.32 kg/m^3. The only reason the hand specimen deviates from the norm is due to its extremely small dimension in comparison to the standard and somewhat asymmetrical shape. The bulk density test conducted on 33 brick samples from Bhaktapur District ranges from 1.55 g/cm^3 to 2.82 gm/cm^3 (Shrestha, 2019). Bhattarai et al. (2018) conducted a test on seven brick samples and discovered the bulk density with in the ranges from 1.2g/cm^3 to 1.8g/cm^3. Similarly to this, a test conducted by Chapagain (2020) on 49 samples of 17 grades revealed that the bulk density value for these samples ranges from 1.1 to 1.4 gm/cm^3. And, the research study revealed that high-quality bricks 'A' and 'M' have bulk densities of 1.949 and 1.944 gm/cm^3, respectively. With the exception of these two, all 14 brick samples match the requirements and shared some similarities with earlier discoveries. Also, brick became more compact as bulk density rose, resulting in lesser porosity and higher strength and durability. Brick compaction is significantly influenced by the firing temperature. It is a result of the increased consolidation between brick sample particles with increased temperature (Sutcu et al., 2015).

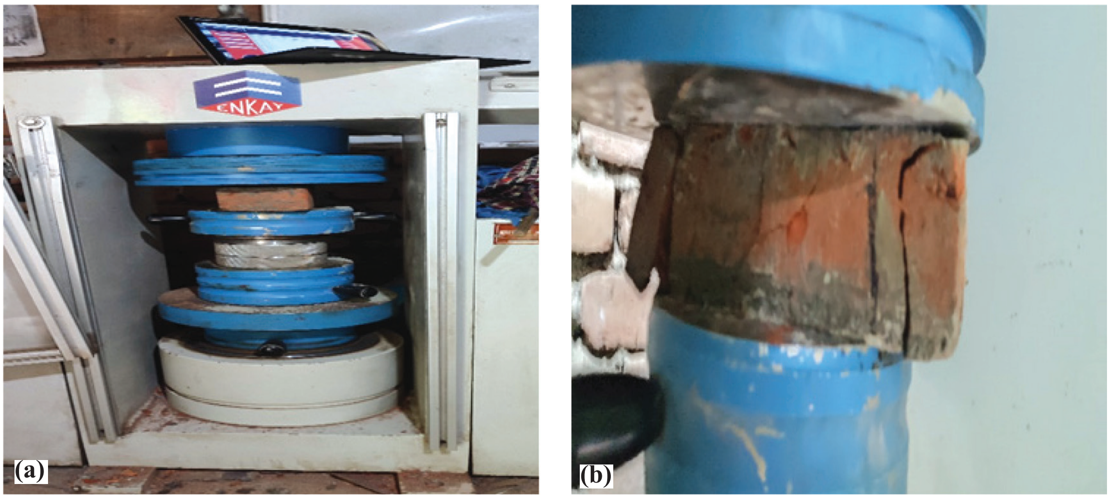

Fig. 4: Laboratory test of compressive strength for brick samples using Enkay software (a) compressive strength testing, (b) breaking of bricks after applying load.

Table 1: Dimension of brick samples measured brick manufacturing industries.

	J			O			S			A			B			M			D	
L	B	H	L	B	H	L	B	H	L	B	H	L	B	H	L	B	H	L	B	H
219	100	53	215	98	60	212	102	57	233	109	63	206	98	60	215	102	53	204	96	56
211	97	50	219	100	60	216	96	59	222	108	58	212	98	59	206	98	58	204	96	55
212	100	60	223	103	60	214	100	59	228	112	61	212	102	57	210	102	54	205	95	53
211	98	55	210	94	53	212	101	56	222	112	61	210	99	60	207	103	53	199	95	57
215	98	53	211	97	60	216	101	56	222	108	56	209	101	60	206	100	54	204	94	57
205	94	59	210	93	53	214	97	55	222	109	59	208	97	55	200	102	58	205	99	58
208	99	60	211	96	60	208	101	58	220	100	64	213	101	58	218	104	60	207	100	54
211	100	59	209	95	56	215	100	59	222	96	60	212	107	57	216	105	60	212	100	58
213	100	60	208	95	52	215	100	57	220	102	63	209	99	57	214	103	59	209	100	59
210	99	59	208	97	55	213	103	59	220	100	61	208	108	59	210	102	60	205	93	55
219	102	56	222	103	62	218	102	59	229	111	65	221	97	5.9	210	100	57	199	95	62
211	100	58	214	102	60	216	105	58	230	107	61	218	103	58	213	102	57	202	94	56
218	103	59	208	96	56	218	101	57	227	110	64	218	102	54	209	10	60	203	96	5.7
218	101	64	223	107	56	218	99	61	228	110	60	220	100	60	213	104	60	206	100	58
218	101	64	217	102	56	217	101	58	232	114	58	217	103	56	209	100	56	210	100	58
220	105	60	219	98	49	216	101	60	224	109	63	217	102	59	204	93	58	208	99	57
211	100	58	215	103	55	215	100	59	224	110	58	217	106	60	208	96	58	206	100	54
212	102	60	219	97	58	218	106	60	221	108	54	220	103	60	204	89	58	208	95	58
214	100	60	225	102	57	211	104	58	228	108	56	220	105	59	200	94	56	210	98	55
212	99	59	222	103	53	213	105	59	227	107	60	207	102	59	204	97	57	210	97	58

Note: L = length (mm), B = breadth in mm, H = height in mm

Brick is subjected to a water absorption test to determine how much moisture it can absorb under extreme circumstances. A low value of water absorption is a sign of excellent compressive strength, long-lasting use, and high-quality bricks. Among seven brick manufacturing industries, ‘A’ brick sample has the lowest water absorption capacities for high quality bricks and ‘D’ has the lowest water absorption capacities for low quality and handmade brick samples (Fig. 7). Brick sample from 'J' has the maximum water absorption capacity for handmade samples (HM) and low-quality brick (LQ), and 'S' has the highest water absorption capacity for high-quality brick (HQ). Shrestha, (2019) on 33 brick samples found a water absorption value of 8.80 to 23.93 %. Chapagain (2020) calculated water absorption values within the range of 5–30 % based on 49 brick samples tested from various districts of Nepal. Bhattarai et al. (2018) found findings ranging from 10% to 28% in seven Kathmandu brick samples. While the water absorption capacities of 14 brick samples from seven different brick businesses varied from 9.3589 to 16.895%. Additionally, the value for hand specimens ranged from 9.9322 to 13.4283%, which is consistent with earlier findings at the various locations previously mentioned. According to IS 1077:1992, a water absorption value of 20% or less by weight is appropriate for classes up to 12.5 and 15% for higher classes. The test results showed that the water absorption value lies within the range of 20% or less by weight and 15% by weight for the respective class to which it belongs.

Also, the strength of the brick will decrease as the porosity increases. Bricks with less porosity will be more sensitive to temperature changes and more resistant to slag attacks. They will transmit heat more effectively. ‘S’ and ‘J’ have the highest apparent porosity values for high-grade and low-grade brick samples, whereas ‘A’ has the lowest apparent porosity value for high grade brick samples among the 14 brick samples from seven different brick industries. For 14 brick samples, the apparent porosity ranged from 18.25 to 27.95%. ‘J’ has the largest apparent porosity (27.07%) and ‘D’ has the lowest (24.33%) for the hand specimen (Fig. 8). According to Shrestha (2019), the apparent porosity value is between 19.28 and 53.99%. According to Chapagain (2020), the test findings show an apparent porosity at between 10% and 40%. Similar to this, Bhattarai et al. (2018) demonstrated that the test result fell between 17 to 33%. It is discovered that there is a slight similarity in the results between Bhattarai et al. (2018) and present findings.

The correlation between water absorption capacity and apparent porosity between low-quality, high-quality, and handmade brick samples showed an R^2 value within the range of 0.8568 to 0.9988 (Fig. 9). The higher value of R showed that there is a good relationship between the water absorption capacity and apparent porosity, and indicates that the brick sample absorbs the required water with a higher value of apparent porosity. With R-values of 0.9858 for high-quality brick, 0.9993 for low-quality brick, and 0.9256 for a handmade brick sample, it can be seen that low-quality brick has the greatest propensity to absorb enough water due to its higher apparent porosity value.

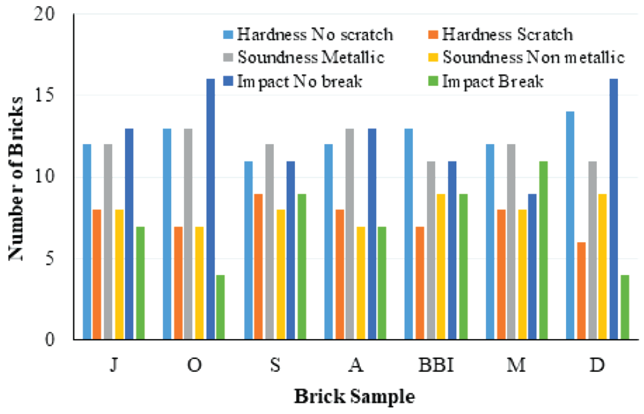

Fig. 5: Hardness, soundness, and impact test result for twenty samples from each brick industries.

Under the mechanical method of fire brick testing, the compressive strength of 14 brick samples from seven brick industries was examined. IS 3495 (Part 1): 1992 was followed for this purpose. The compressive strength for 14 brick samples ranges from 7.02 MPa to 23.49 MPa (Fig. 10). For high-quality brick samples, ‘A’ has the highest compressive strength of 23.49 MPa while ‘S’ has the lowest value of 10.95 MPa. Similar results may be seen for low-grade brick samples, where ‘J’ has the lowest value of 7.02 MPa and D has the highest value of 14.13 MP. The compressive strength of 33 brick samples from the Bhaktapur District ranges from 7.83 MPa to 22.10 MPa (Shrestha, 2019). The compressive strength of 49 brick samples of 17 grades was reported to range from 3.35 to 10.53 MPa (Chapagain, 2020). On seven Kathmandu brick samples, the compressive strength ranged from 5 to 23 MPa (Bhattarai et al., 2018). The test results revealed a modest similarity between Shrestha (2019) and Bhattarai et al. (2018) compressive strength value and our findings. The test results also followed the NBC 109-1994 standard which state that the brick's crushing strength must not be less than 3.50 MPa.

Additionally, there is a strong association between the bulk density, apparent porosity, and water absorption capacity of all the examined fired clay bricks. The association and comparison between water absorption capacity, bulk density, and apparent porosity of high-quality brick, low-quality brick, and handmade brick from seven brick industries are studied. Raising the bulk density is shown to reduce both the water absorption and apparent porosity of the brick samples (Figs. 11, 12, 13). The fact that the low density of brick samples is strongly related to their high water absorption capacity and apparent porosity with poor particle packing in brick samples lends validity to these findings. In general, it is thought that burnt bricks will have higher than anticipated bulk densities and compressive strengths, as well as lower than anticipated water absorption capacities and apparent porosities. Bulk density and compressive strength tests between different samples from seven different industries also support the above fact.

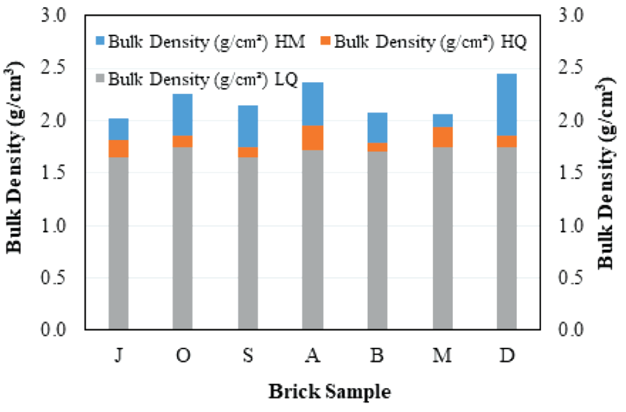

Fig. 6: Bulk density estimation chart for different brick samples.

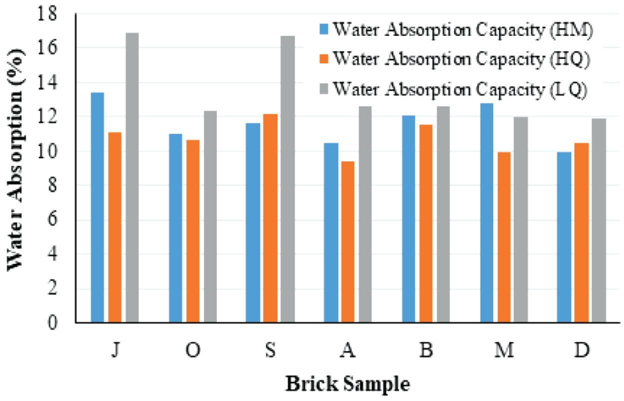

Fig. 7: Water absorption capacity of different brick samples.

The compressive strength and bulk density of the brick samples are directly correlated. The association of bulk density and compressive strength of seven brick samples from seven brick manufacturing industries was shown in figures 14 and 15. When the bulk density of brick samples rises, their compressive strength also rises. It signifies that they are directly proportional to each other. Therefore, it can be suggested that in order to improve mechanical properties i.e. compressive strength of the clay bricks, efforts should be concentrated on reducing both the water absorption and the apparent porosity as well as on increasing bulk density. This is because the physical properties are largely responsible for the improvement of all ceramic bodies, including clay bricks.

Compressive strength test of handmade brick samples was prohibited. The dimension of handmade brick was extremely low and has a small height. When the load was applied to the hand specimen, because of its height large amount of load has to be applied until it touched the brick sample surface. Hence extremely high stress was recorded which indicates the falseness of the result. Handmade samples have maintained a strong association between bulk density, water absorption capacity, and apparent porosity same as 14 samples collected from seven brick manufacturing industries (Fig. 13).

Also, there is a strong association between the brick samples' apparent porosity, compressive strength, water absorption, and bulk density. The changes in bulk density, water absorption capacity, and apparent porosity as the function of its mechanical properties i.e., the compressive strength are shown in figures 16, 17. The bulk density of high quality brick samples has the highest correlation values than the other two parameters. In contrast to this, the water absorption capacity and apparent porosity R-value of high-quality bricks are less than that of low-quality bricks. It indicates that with the increase in compressive strength, and bulk density, low-quality bricks absorb more water than high-quality brick samples. Hence, with the increase of compressive strength, bulk density shows a positive increment, whereas water absorption capacity and apparent porosity showed a negative response which indicates the goodness of the brick sample to be used as construction materials

The field test results and laboratory results showed slight contrast. It is because of the fact that for field test sample was randomly collected from various piles of bricks having various strengths. But for laboratory test, two samples one of high quality and one of low quality was sampled. Samples of high quality and low quality can be distinguished either by seeing

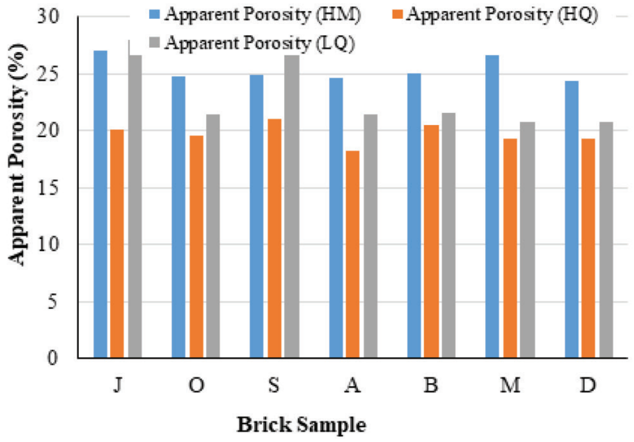

Fig. 8: Apparent porosity of different brick samples.

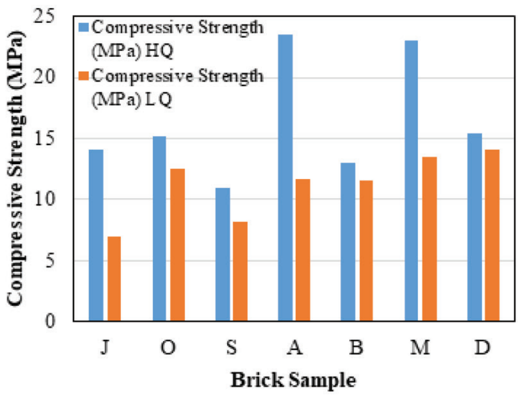

Fig. 10: Compressive strength of different brick samples.

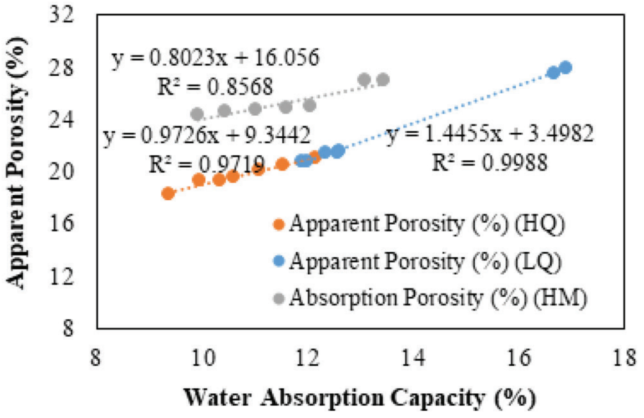

Fig. 9: Correlation between water absorption capacity and apparent porosity of the high-quality, low-quality, and handmade brick sample.

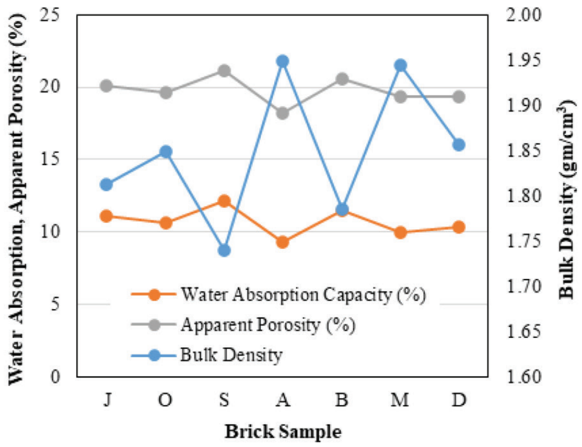

Fig. 11: Variation between water absorption capacity and apparent porosity with bulk density for high-quality brick.

color, and soundness or by examining the compaction between the mineral grains after breaking the bricks.

Mineralogical analysis

Mineralogical analysis was carried out using the X-Ray diffraction technique. XRD was performed for seven brick samples from seven different brick manufacturing industries named J, O, S, A, B, M, and D. Bragg's law was used for this purpose which states that $n\lambda= 2d\sin\theta$. From the value of q and using the Braggs law, the value of d was calculated. The d value and 2θ value were correlated to the standard given value (ASTM Powder Diffraction Data file) (Lindholm, 1987) and the phase minerals were identified.

The XRD test results i.e. the secondary data of the 'O' brick samples obtained from the Nepal Academy of Science and Technology are shown in Figure 18 as a sample representation of seven brick manufacturing industries.

The mineralogical analysis of seven brick samples indicates the presence of quartz, berlinite, and hematite as identified mineral phases. 2 theta (θ) value up to 40° and their d value are observed and analysed for phase mineral identification. The comparison of the XRD pattern of the mineral phase indicates the presence of hematite along with quartz from the sample of 'J' brick manufacturing industry (Fig. 19). Hematite was observed at 24.197°, 33.227°, 35.703° 2θ value and 3.6843, 2.7008, 2.5191 d value. And quartz was observed at 20.917°, 26.696°, 36.650°, 39.528° 2θ value and 4.2435, 3.3366, 2.4500, and 2.2780 d values. Similarly, berlinite along with quartz was observed in the sample of the 'S' brick manufacturing industry. Quartz was absorbed at 20.874°, 26.662°, 36.573°, 39.504° 2θ and 4.2522, 3.3408, 2.4550, and 2.2793 d values. Also, berlinite was observed at 20.721°, 26.398°, 32.273°, 36.299°, 39.111° 2θ values and 4.2832, 3.3738, 2.7785, 2.4729, and 2.3070 d value. The XRD pattern of 'O' brick manufacturing industries indicates the presence of quartz as the phase mineral. Quartz was observed at 20.917°, 26.696°, 36.650°, and 39.528° 2θ with 4.2435, 3.3366, 2.4500, and 2.2780 d values. XRD pattern of samples from 'A' and 'B' brick manufacturing industries indicate the presence of quartz as the phase mineral. Quartz was observed at 20.970°, 26.696°, 36.650°, 39.528° 2θ and 4.2435, 3.3366, 2.4500, and 2.2780 d values. The presence of berlinite as a phase mineral was observed in the sample of the 'M' brick manufacturing industry. The phases were observed

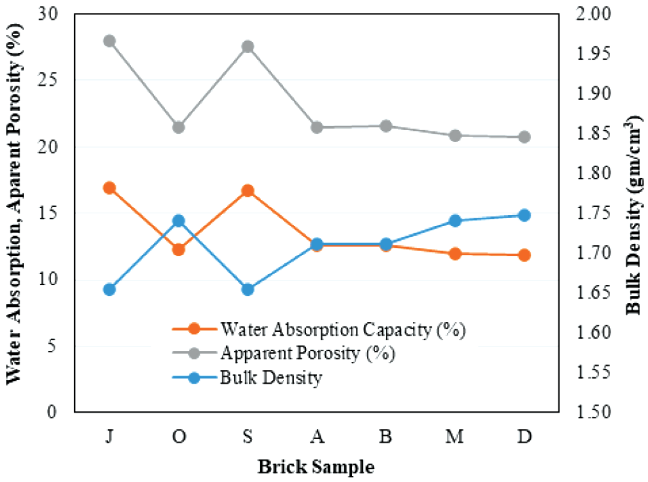

Fig. 12: Variation between water absorption capacity and apparent porosity with a bulk density of low-quality bricks.

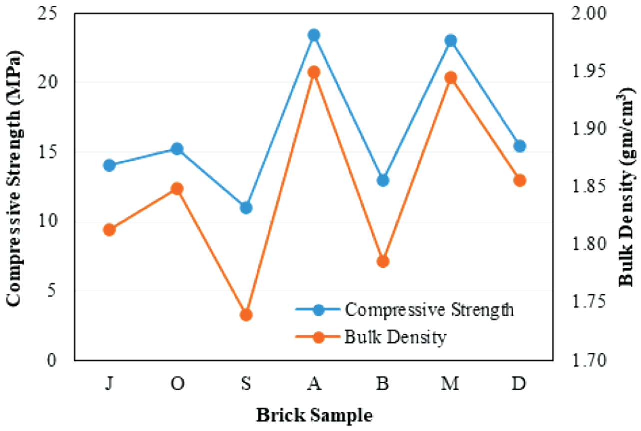

Fig. 14: Variation between compressive strength and bulk density of the high-quality brick from different brick samples.

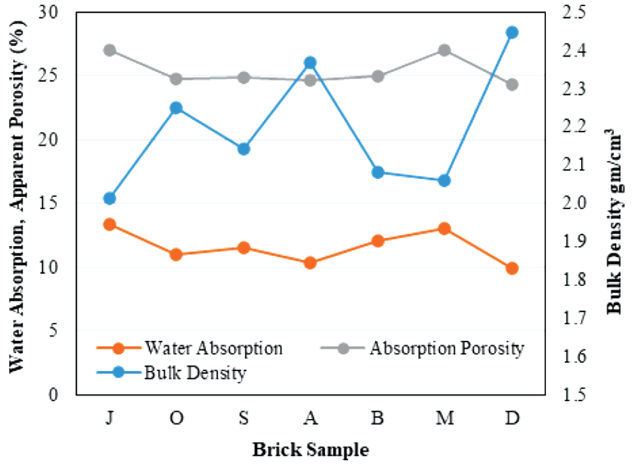

Fig. 13: Variation between water absorption capacity and apparent porosity with a bulk density of a handmade brick sample.

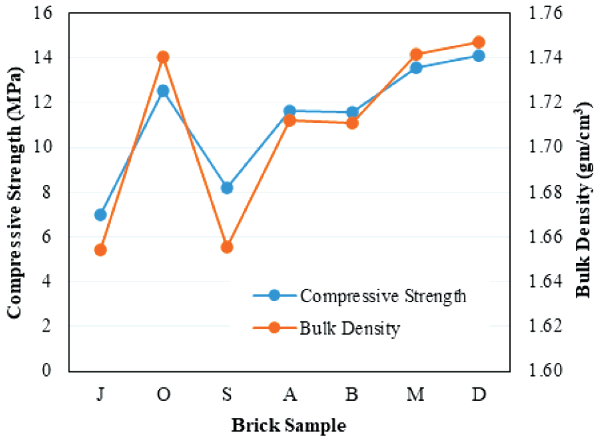

Fig. 15: Variation between compressive strength and bulk density of the low-quality brick of different brick samples.

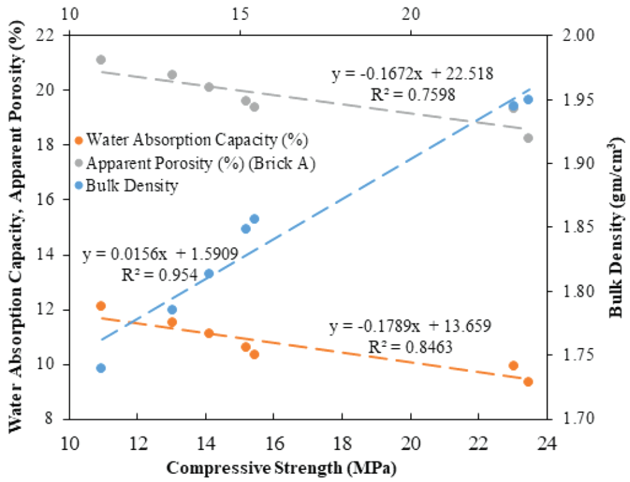

Fig. 16: Change in bulk density, water absorption capacity, and apparent porosity as a function of compressive strength for high-quality bricks.

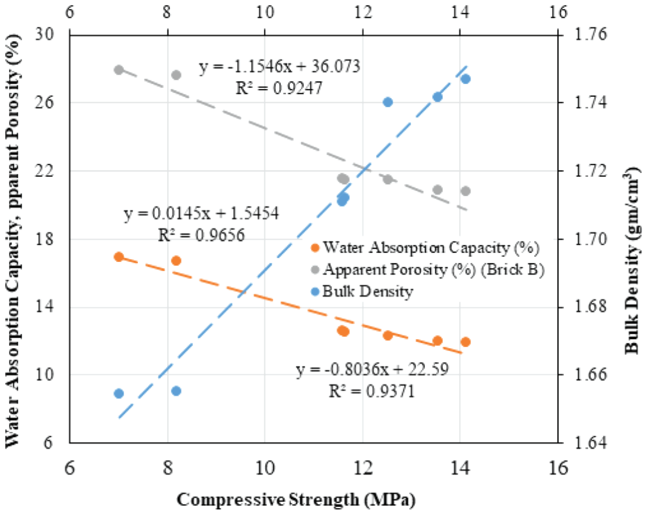

Fig. 17: Change in bulk density, water absorption capacity, and apparent porosity as a function of compressive strength for low-quality bricks.

at 20.782°, 26.405°, 32.283°, 36.314°, and 39.023° 2θ with 4.2815, 3.3726, 2.7776, 2.4719, and 2.3063 d value. The XRD pattern of 'D' brick manufacturing industry indicates the presence of quartz as phase mineral. Quartz was observed at 20.926°, 26.729°, 36.573°, and 39.504° with d value of 4.2522, 3.3408, 2.4550, and 2.2793.

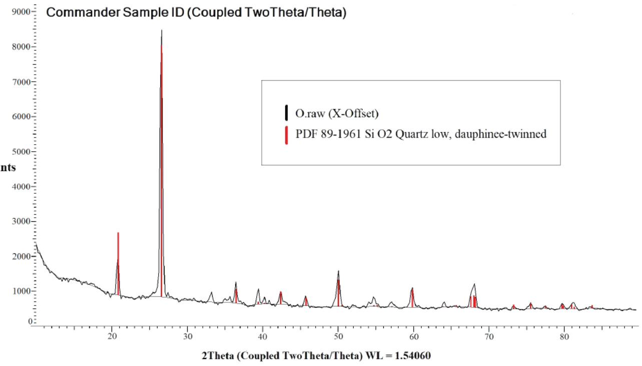

Fig. 18: XRD pattern of 'O' brick samples using secondary data obtained from Nepal Academy of Science and Technology (NAST).

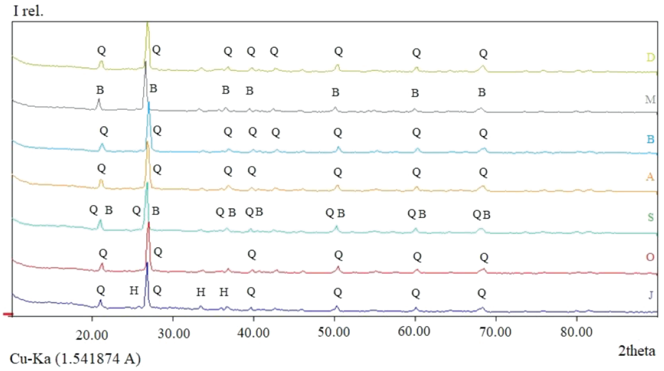

Fig. 19: Correlation of the XRD pattern of brick samples from different brick manufacturing industries 'J', 'O', 'S', 'A', 'B', 'M', and 'D' considering 2θ value correlating with ASTM Powder Diffraction Data file.

The mineralogical investigation on six brick samples CAB–5, RCB-4, BRB-3, CCB-7, BSB-11, and NTB-17 identified quartz, feldspar, spinel, primary mullite, hematite, and mica mineral muscovite as phase minerals (Chapagain et al., 2020). Because of the aluminum-rich spinel phase and mullite phase in RCB-5, and CAB-5, the firing temperature was found to be 1000°C to 1100°C. However, in the other four brick samples, a primary mullite phase was absent and a muscovite phase was observed in CCB-7 and BSB-11 which indicate the firing temperature was either less than 900°C or 900°C to 1000°C. The mineralogical study on three historical bricks from Patan, Nepal indicates the presence of quartz, cristobalite, mullite, feldspars, and different clay minerals as phase minerals (Shrestha, 2017). The presence of mullite phase rather than spinel phase in all tested bricks showed that the firing temperature must be 1100°C or high.

From our research work, it was found that the 'S' brick sample has quartz low with dauphine twinned and berlinite. Quartz low was stable at 573˚C and dauphine twinned of quartz was formed at 573°C at alpha beta inversion. While berlinite was formed above 815°C. XRD of 'J' indicates the presence of quartz low, dauphine – twinned formed under 573°C, and hematite phase. The presence of a hematite phase indicates that the temperature ranges from 850°C to 1150°C. 'M' XRD pattern showed the presence of the berlinite phase. XRD of the 'O' sample indicates the presence of quartz (low) stable at 573°C.

CONCLUSIONS

A strong association between the mechanical property of compressive strength and the different physical qualities of brick samples are found. With the increasing bulk density and decreasing water absorption capacity and porosity of brick samples, the compressive strength increases exponentially. This phenomenon is supported by each brick sample of high–quality, low–quality, and hand-made brick specimens.

With water absorption capacity ranging from 9.63–16.89% and compressive strength from 7.020–23.06 MPa, six brick samples belong to up to 12.5 class and others to the higher class of brick samples. It is found that the improvement of the compressive strength is dependent on reducing both the porosity and water-holding capacity while increasing density. Similarly, mineralogical analysis indicates the presence of quartz, quartz low, dauphine–twinned, berlinite, and hematite phases which is a firing temperature of about 573°C to 1150°C. Thus, on the basis of physical, mechanical, and XRD analysis for firing temperature all the bricks produced from the brick industry of the Chitwan District are of good quality and can be used as construction material.

ACKNOWLEDGEMENT

Author would like to acknowledge the Department of Geology, Tri-Chandra Multiple Campus, Nepal Academy of Science and Technology (NAST), Smart Drilling & Testing Pvt. Ltd. and their staffs for providing the necessary laboratory and helping out with providing other materials and facilities to carry out the research works. I would like to thank Ms. Indira Dharel for her helps during the fieldwork and laboratory works.

REFERENCES

ASTM D422–63 (Re–approved 1990), Standard Test method for particle-size analysis, American Society for Testing and Materials, Philadelphia, USA.

Azam, R., Riaz, M. R., Haq, E. U., Shihata, A., and Zawam, M., 2022, Development of Quality Assessment Criteria for Burnt Clay Bricks of Different Ages Based on Ultrasonic Pulse Velocity Test. Buildings 2022, v. 12, pp. 1069.

Bhattarai, J., Ghale, D. B., Chapagain, Y. P., Bohora, N. B., and Duwa, N., 2018, Study on the physical and mechanical properties of ancient clay brick samples of Kathmandu Valley. Nepal Tribhuvan University Journal, v. 32, pp. 1–18.

Chapagain, Y. P., Sapkota, S., Ghale, D. B., Bohora, N. B., Duwal, N., and Bhattarai, J., 2020, A case study on mineralogy and physico – mechanical properties of commercial bricks produced in Nepal. SN Applied Sciences, v. 2, pp. 1–14.

Cultrone, G., Sebastian, E., and De la Torre, M. J., 2005, Mineralogical and physical behaviour of solid bricks with additives. Construction and Building Materials, v. 19, pp. 39–48.

Danso, H. and Akwaboah, M., 2021, Assessment of the quality of burnt bricks produce in Ghana: The case of Ashanti region. Case Studies in Construction Materials, v. 15, p. e00708.

Ekinci, A. and Ferreira, P. M. V., 2012, Effects of fibre reinforcement in the shrinkage behaviour of compacted clay. 3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering.

Elert, K., Cultrone, G., Navarro, C. R., and Pardo, E. S., 2003, Durability of bricks used in the conservation of historic buildings – influence of composition and microstructure. Department of Mineralogy and Petrology, University of Granada, Fuentenueva. Journal of Cultural Heritage, v. 4, pp. 91–99.

IS 1528(Part 15), 2007, Method of sampling and physical tests for refractory materials. Bureau of Indian Standards, New Delhi.

IS 3495 (Part 1-2), 1992, Method of tests of burnt clay building bricks. Bureau of Indian Standards, New Delhi.

IS 3495 (Part 2), 1992, Method of tests of burnt clay building bricks. Bureau of Indian Standards, New Delhi.

IS 875(Part 1)-1987, Code of practice for design load (other than earthquake) for buildings and structures. Bureau of Indian Standards, New Delhi.

IS1077, 1992, 2007, Common Burnt Clay Building Bricks – Specification.

Karaman, S., Ersahin, S., and Gunal, H., 2006, Firing temperature and firing time influence on mechanical and physical properties of clay bricks. Jour. Sci. and Indus. Res., v. 65, pp, 153–159.

Kazmi, S. M. S., Abbas, S., Munir, M. J., and Khitab, A., 2016, Exploratory study on the effect of waste rice husk and sugarcane bagasse ashes in burnt clay bricks. Journal of Building Engineering, v. 7, pp, 372–378.

Kornmann, M., 1986, Clay Bricks and Roof Tiles, Manufacturing and Properties, USA.

Laefer, D. F., Boggs, J., and Cooper, N., 2004, Engineering Properties of Historic Brick: Variability Considerations as a Function of Stationary versus Nonstationary Kiln Types. Journal of the American Institute for Conservation, v. 43, pp. 255–272.

Lindholm, R. C., 1987, Mineral identification using X-ray diffraction. In A Practical Approach to Sedimentology, pp. 124–153.

Lourenco, P. B., Fernandes, F. M., and Castro, F., 2010, Handmade clay bricks: Chemical, physical and mechanical properties. International Journal of Architectural Heritage, v. 4, pp. 38–58.

Manandhar, U. and Dangol, S. 2013, Study on Evaluating Energy Conservation Potential of Brick Production in SAARC Countries; A Report on Nepal; SAARC Energy Centre. Islamabad, Pakistan.

Mueller, H., Maithy, S., Prajapati, S., Bhatta, A. D., and Shrestha, B. L., 2008, Green brick making manual. Switch Resource Centre and Consultancies for Development.

NBC 109:1994, Nepal National Building Code. Department of Urban Development and Building Construction, Kathmandu.

Nepal, S., Mahapatra, P. S., Adhikari, S., Shrestha, S., Sharma, P., Shrestha, K. L., and Puppala, S. P., 2019, A Comparative Study of Stack Emissions from Straight-Line and Zigzag Brick Kilns in Nepal.

Shrestha, S. and Thygerson, S. M., 2019, Brick Kilns of Nepal: A Non-Governmental Organization Perspective. Open Journal of Safety Science and Technology, v. 9, pp. 1–6.

Shrestha, S. L., 2017, Mineralogical study of historical bricks of Patan, Nepal using XRD and FTIR analysis. International Journal of Advance Research in Chemical Sciences, v. 4, pp. 28–35.

Shrestha, S., 2019, A case study of brick properties manufacture in Bhaktapur. Journal of Science and Engineering, v. 7, pp. 27–33.

Subedi, S. K., 2020, Study of Characteristics of Bricks Produced in Kathmandu, Nepal. American Journal of Civil Engineering, v. 8, pp. 64–76.

Sutcu, M., Alptekin, H., Erdogmus, E., Er, Y., and Gencel, O., 2015, Characteristics of fired clay bricks with waste marble power addition as a building materials. Construction and Building Materials, v. 82, pp. 1–8.

Tsega, E., Mosisa, A., and Fufa, F., 2017, Effects of Firing Time and Temperature on Physical Properties of Fired Clay Bricks. American Journal of Civil Engineering, v. 5, pp. 21–26.

Vekey, C. R., 1998, Brickwork and blockwork. In: Illston, J. M. and Domone, P. (eds.), Construction materials - their nature and behaviour, pp. 251–315.

Weaver, M. E., 1997, Architectural ceramics. Conserving buildings-a manual of techniques and materials, pp. 99–132.