Ancient Forts, Modern Methods: Evaluating the Redesigned Mortar of Ramkot Fort Azad Kashmir

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Abstract:

Ramkot fort was built in the medieval period by Sultan Ghayas-ud-Din. This fort is situated near Mirpur City in a peninsula surrounded by River Jhelum and is experiencing serious deterioration due to environmental and aging effects. There is a dire need to restore the fort so that the cultural identity and historical integrity should be preserved for future generations. Rehabilitating heritage sites helps foster community pride and strengthens local distinctiveness. This paper aims to evaluate the ancient mortar of Ramkot Fort Azad Kashmir. The ancient mortar was analyzed using modern techniques like acid dissolution, sieve analysis, XRD, and XRF. The techniques revealed that the mortar consisted of lime, brick powder, clay, and sand. A newly designed mortar was prepared and tested in terms of density, workability, ease of construction, and mechanical strength. The results revealed that the mortar was highly flowable and had a low density of the order of 1.7 to 1.8 g/cm³. The final flow diameter exceeded the dimensions of the flow table. The 28 days compressive strength was 1.5 MPa. The newly designed mortar was compatible both with brick and stone masonry. The compressive as well as bond strength of re-designed mortar was comparable to that of the modern 1:4 cement sand mortar. Repairing the earliest heritage with an identical mortar as originally used warrants that the restoration respects the historical, structural, and esthetic values of the building. It holds the authenticity and integrity of the heritage site while guaranteeing that the restorations are consistent with the original materials and construction methods.

Keywords:

Ramkot Fort Azad Kashmir, ancient mortar, modern design, evaluation, construction.

1. Introduction:

Ramkot Fort, located in Azad Kashmir, Pakistan, is a historic fortress with a rich and varied past. Perched on a hill overlooking the Jhelum River and directly opposite New Mirpur City, the fort is strategically positioned on the edge of the river near the Mangla Dam. Built by Sultan Ghiyas-ud-Din in the 16th century, Ramkot Fort stands as a significant piece of national heritage. The structure, which has deteriorated over time, was originally constructed over the foundations of an old Hindu Shiva temple. Its strategic location on a hill, encircled by the Jhelum River on three sides, renders it a peninsula and a formidable defensive fortification. Some snaps of the fort are shown in Figure 1.

Figure 1: Ramkot Fort Azad Kashmir Pakistan

2. Literature Review:

Ramkot Fort holds significant historical value, representing various eras of regional history, including the Ghaznavid, Ghurid, Mughal, Sikh, and British periods. Preserving it helps maintain a tangible link to these past civilizations and their architectural styles. Rehabilitation of historic places is practiced safeguarding their historical, cultural, and architectural significance, ensure safety, and promote educational and tourism opportunities. As the fort has deteriorated with age, as shown in Figure 2, preservation efforts are urgently needed.

Figure 2 Deterioration of stone masonry of Ramkot Fort

Talib et al. [1]presented a case study about the characterization of old mortar of Rohtas Fort in Jhelum Pakistan. It was reported in their study that the old mortar was made of lime, clay, red brick powder, and sand. The mortar had a lime-to-aggregate ratio of 1:1.55. The compressive strength of the old mortar was found to be 2.2 MPa, with a porosity of 42%. This higher porosity was identified as the main cause of the deterioration of the mortar. The redesigned mortar was found to have a 28-day strength of 3.7 MPa and a porosity of 35%.. Giandomenico et al. [2] studied the old wall painted plasters in a Church of Matera in Italy. The researchers carefully restored the paintings so that they look good and match the original materials. They used special mixes of lime and sand in different sizes to repair missing parts of the old painted plaster, making sure the new materials fit well with the existing rock and plaster. Hao et al. [3] conducted a comprehensive review of damage assessment and restoration technologies for old structures constructed with bricks and timber. The authors emphasized that restoration plans for old buildings should respect cultural protection rules, focus on sustainability, and consider environmental impacts. The rehabilitation techniques should blend traditional methods with new technologies to keep the buildings valuable and functional for the future. With that intent this research work serves to evaluate the old mortar and to redesign a modern mortar made with old materials and new technologies.

In this work, the old mortar was characterized and a new mortar with the same materials was manufactured in the lab. Once the mortar had been prepared, the material was checked in terms of physical and mechanical properties. In addition, masonry brick and stone walls were constructed with the redesigned mortar to check its compatibility in the modern environment. Ramkot fort is an important heritage of Pakistan, and its restoration with a compatible material will enhance its age and will preserve this building for the present and coming generations.

3. Methodology:

In this research, first the old mortar was characterized through acid dissolution method and by sieving. The old mortar was exposed to 0.1M HCl. The old mortar was immersed in the solution for 24 hours. By the end of this period, the aggregates had completely settled, leaving clear water above. The solution dissolved the binder content, which was filtered through a filter paper. The aggregates were retained and weighed. This segregated the binder and aggregated content. Both filtrate and aggregates were weighed. The filtrate was heated in an oven at 40ºC for one day. The water evaporated leaving behind the salt content, which was weighed. Further the aggregate portion was dried and sieved. The aggregates were passed through ASTM sieves: No. 4, No. 10, No. 16, No. 20, No. 40, No. 60, No. 100, No. 200, and a pan. The sieving provided us with the proportion of sand, brick particles and clay present in the aggregates. The binder to aggregates ratio and the proportion of different aggregates are presented in Table 1. The broken brick pieces were categorized based on their size, with larger fragments being retained on the sieve # 4 (4.75 mm sieve), followed by smaller broken pieces retained on the sieve # 10 (2 mm sieve) and sieve # 40 (0.425 mm sieve). The sand particles were further classified, with those retained on sieve # 100 (0.15 mm sieve) and sieve # 200 (0.075 mm sieve). Finally, the clay particles, being very fine, passed through all these sieves, indicating their small size and ability to pass through the sieve 200 sieve.

Table 1: Composition of old mortar of Ramkot Fort

Binder to aggregates ratio	1:1.8
Sand	38.5%
Brick particles	39.5%
Clay	22%

A new mortar was developed with the same local materials as found in the above test methods. The chemical composition of the new mortar as per composition described in Table 1 is provided in Table 2. All the quantities are in Kg except water to binder ratio. The water-to-binder ratio was determined using a hit and trial method, where different ratios were tested to achieve the desired consistency of the mortar (0.4 to 0.7). The consistency was carefully observed by preparing test batches with varying amounts of water relative to the binder. Each batch was mixed, and its workability was assessed by performing the flow table test. The ratio that produced a workable, smooth, and consistent mortar was selected for further use in the formulation.

Table 2: Composition of materials in one cubic meter of modern mortar

	Lime	Sand	Brick particles	Clay	Water	Water to binder ratio
Quantity (kg)	278	192	198	110	287	0.5

'The materials used for the mortar mix, including lime, clay, red brick powder, and sand, are shown in Figure 3.shown in Figure 3. The mortar was cast, and the prepared mortar and the historic mortar are compared in Figure 4.

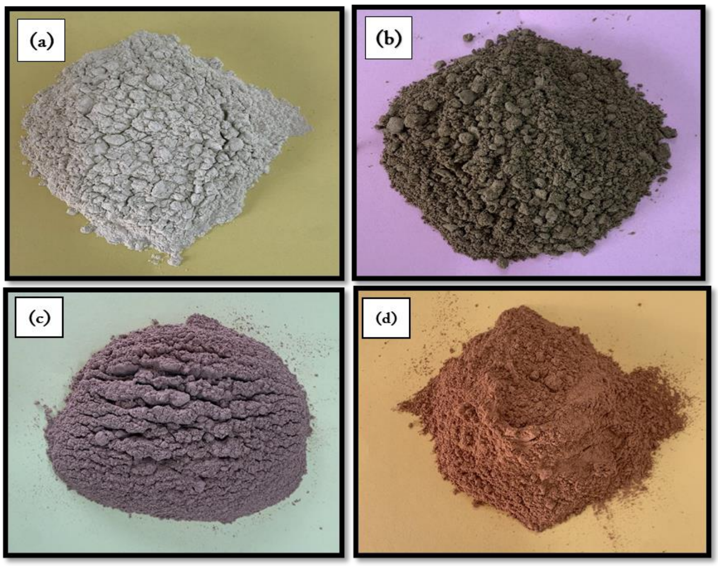

Figure 3: Ingredients of modern mortar : (a) Lime (b) Clay (c) Sand (d) Brick Powder

Figure 4: Comparison of old mortar (right) and modern mortar (left)

Mortar cubes and prisms were cast, which are shown in Figure 5. The newly designed mortar was evaluated in terms of physical and mechanical properties. The flowability was measured by ASTM C1437-20 method [4]. The density was determined through ASTM C188-17 method [5]. The compressive strength was measured through compressive strength by ASTM C1314-21 method [6], and the water absorption was examined through ASTM C1403-15 [7].

Figure 5 Prepared cubes (on left) and prisms (on right)

In the flow table test, the mortar mixes were filled in two layers in a cone as shown in Figure 6. After compacting with a rod, the cone was lifted and after raising and dropping the table 15 times, the final diameter of the mix was measured. The density was determined by measuring the mass and volume of the specimen and by using the equation (1):

$$\gamma = \frac{m}{V} \tag{1}$$

Where γ is mass density, m is mass and V is the volume of the specimen. The compressive strength of the specimens was measured by using Control Wizard Auto machine. The specimens measuring 5x5x5 cm in dimensions were subjected to compressive load aftercuring for 28 days. The load at failure was calculated by using equation (2):

$$fc' = load\ at\ failure/cross\text{-}sectional\ area \tag{2}$$

For measuring water absorption, the specimens were dried in an oven for 24 hours at a temperature of 110ºC. After 24 hours of oven drying, the dry mass was measured, and the specimens were immersed in water and saturated mass was determined after every four hours. When the change in mass seized, the specimens were surface dried and final mass was calculated by using equation (3):

$$W_a = \frac{(m_{sd} - m_d)}{m_d} \tag{3}$$

Where W_a is the water absorption, m_{sd} is the surface dried mass and m_d is the dry mass of the specimen.

4. Results:

The flow table test is shown in Figure 6. The flow exceeded the limits of the flow table, as illustrated in the Figure. This indicates that the material exhibited high workability (while maintaining an excellent cohesion), which prevented the measurement of a flow diameter.

The average density was measured as 1.67 g/cm^3. The density as given above was an average of five values. The compressive strength was found to be 1.5 MPa. The value is an average of five results. The mean water absorption was found out to be 29.75. All the results were determined at an age of 28 days.

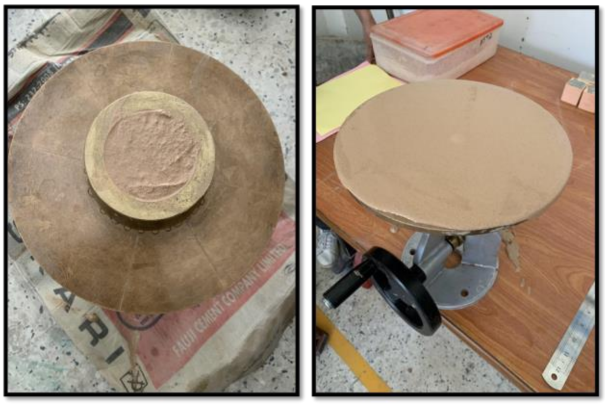

Figure 6: Flow Table test

5. Discussion:

As can be seen in Figure 5, the mix was highly flowable. The high flowability is attributed to lime, clay and brick powder. The evidence of brick particles was also confirmed in historic Ottoman empire buildings [8]. The current study confirmed the presence of clay in addition to brick powder in lime mortar of medieval structures of the sub-continent. The brick particles enhance the flow of lime mortar by providing a rough, granular texture that increases its workability and reduces viscosity. The granular structure helps to reduce internal friction between particles, allowing the mix to move more freely [9], [10]. Granular particles can lower the apparent viscosity of the mix by interrupting the formation of strong inter-particle bonds. Additionally, the irregular shape of the brick particles can contribute to better packing within the mortar, which reduces voids and makes the mix more cohesive. This reduction in friction and the improved cohesion lowers the overall viscosity of the mortar, enabling it to flow more easily while maintaining a consistent and workable texture. This improves the mortar's ability to spread and bond effectively during application[11]. The addition of raw clay enhances the flow of a mix by increasing its plasticity and workability, allowing the mixture to be more easily spread and molded. The fine particles also help to fill voids and improve the mortar's cohesiveness and adhesion[12]. The density of the mortar is 1.67 g/cm^3. The density of modern cement sand mortar is about 2 g/cm^3. The old mortars based on lime in mortar were light weight. The low weight is attributed to the low specific gravities of the constituents. All the constituents are sufficiently lighter than the cement, which lowered the overall density of the mortar [13]. The modern cement sand mortars with a ratio of 1:4 have a compressive strength of 2-4 MPa at 28 days [14], [15]. Lime is inferior in strength than cement and as such the strength is also reduced. The lime sets because of carbonation, which is a slow process, and which also leads to a porous structure of the material[16]. This ultimately reduces the strength. Since lime enhances the porosity of the material, it has more water absorption capacity than that of a cement sand mortar. The water absorption of 29.75% is significantly high, suggesting a porous mix. This characteristic can be beneficial for heritage applications, as it enhances breathability and allows moisture regulation, which is crucial for the preservation of historical structures. However, it could also be a shortcoming in environments requiring high durability or water resistance. It is important to note that this value corresponds to a 28-day curing period, and lime mortars cure more slowly compared to cement mortars. Over time, the water absorption might decrease as the lime continues to carbonate and strengthen, potentially altering the material's performance characteristics.

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6. Conclusion:

Based on this experimental study, the conclusions are put forward as follows:

1. The old mortar of Ramkot Fort comprised of lime, sand, clay, brick particles and water. The lime to aggregates ratio was 1:1.8.
2. A water to binder ratio of 0.5 gave a high flowability, which is attributed to the presence of clay and brick powder. The enhanced flowability ensures that the mortar can easily fill narrow joints, cracks, and intricate spaces in the historic masonry of the fort. This facilitates effective repair and restoration without leaving voids.
3. The mortar has a density of 1.67 g/cm^3, which is 17% lesser than the modern cement sand mortar (1:4). Lower density often correlates with higher porosity, which is beneficial for historic structures as it allows moisture to evaporate, preventing damage due to water retention or freeze-thaw cycles.
4. The mortar has a one-month compressive strength of 1.3 MPa, which is 35% lesser than that of the modern 1:4 cement sand mortars. The reduced strength aligns with the traditional materials used in the fort's original construction, ensuring better compatibility and minimizing the risk of stress that could occur if stronger modern mortars were used.
5. The mortar has a one-month water absorption of 29%, which is 100% higher than that of the modern 1:4 cement sand mortars (15%). A more porous mortar can help regulate the flow of moisture in and out of the building, which is crucial for preventing water-related damage like efflorescence or freeze-thaw cycles. This characteristic is often desirable in historical structures where controlling moisture and maintaining a stable environment is a priority.

7. References:

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