

CHARACTERISTICS AND DESIGN OF INONG BALEE FORT BINDING MORTAR FOR RESTORATION PURPOSES

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Abstract: Inong Balee Fort is one of the Islamic Kingdom of Aceh heritage built-in 1599 by Admiral Malahayati but several parts of the fortress wall have currently been damaged and the stone removed. Indonesian Government plans to restore the fort and this makes it necessary to examine the characteristics of the fortress mortar with a focus on the chemical composition and mineralogical elements. Therefore, mortar powder samples obtained from the fort walls were tested through X-Ray Diffraction (XRD) and the results showed the main composition of mortar is CaCO_3 and SiO_2 from a mixture of lime and sand while the others are P_2O_5 , MgCO_3 , and Al_2O_3 . Meanwhile, two mortar mixtures including 1 lime: 2 sand and 1 cement: 2 lime: 3 sand were designed for restoration purposes and they were both found by the XRD analysis results to have a diffraction pattern similar to Inong Balee Fort mortar. However, mortar with 1 lime: 2 sand has a very low compressive strength subsequently it does not meet the specifications of the SNI 6882:2014 and ASTM C270-19a while mortar with 1 cement: 2 lime: 3 sand has a compressive strength which meets the specifications. Therefore, a mortar with 1 cement: 2 lime: 3 sand is recommended to be used for the restoration of Inong Balee Fort.

Keywords: mortar; Inong Balee Fort; characteristics; compressive strength; restoration

Abstrak: Benteng Inong Balee merupakan salah satu peninggalan Kerajaan Islam Aceh yang dibangun pada tahun 1599 oleh Laksamana Malahayati. Saat ini banyak bagian dinding pasangan batu benteng tersebut sudah rusak dan batunya sudah terlepas dari ikatan mortar. Pemerintah Republik Indonesia berencana melakukan restorasi benteng tersebut. Oleh karena itu perlu diteliti karakteristik mortar pengikat dari pasangan batu benteng tersebut, berupa kandungan senyawa kimia dan mineralnya. Metode yang digunakan untuk karakterisasi adalah dengan melakukan pengujian X-Ray Diffraction (XRD) terhadap bubuk sampel mortar yang diambil dari dinding benteng. Hasil pengujian menunjukkan bahwa komposisi utama mortar pengikatnya adalah CaCO_3 dan SiO_2 yang menunjukkan bahwa mortar tersebut terbuat dari campuran kapur dan pasir. Disamping itu juga terdapat kandungan senyawa P_2O_5 , MgCO_3 dan Al_2O_3 . Selanjutnya untuk keperluan restorasi didesain 2 campuran mortar, yaitu mortar dengan campuran 1 kapur : 2 pasir dan mortar dengan campuran 1 semen : 2 kapur : 3 pasir. Hasil analisis XRD menunjukkan bahwa kedua campuran tersebut mempunyai pola difraksi yang mirip dengan Benteng Inong Balee. Akan tetapi mortar dengan campuran 1 kapur : 2 pasir mempunyai kuat tekan yang sangat rendah sehingga

tidak memenuhi spesifikasi Standar SNI 6882:2014 dan ASTM C270-19a, sedangkan mortar dengan campuran 1 semen : 2 kapur : 3 pasir mempunyai kuat tekan yang memenuhi spesifikasi Standar SNI 6882:2014 dan ASTM C270-19a, sehingga mortar ini disarankan digunakan untuk keperluan restorasi Benteng Inong Balee.

Kata kunci: mortar; Benteng Inong Balee; karakteristik; kuat tekan; restorasi

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Introduction

Several historical buildings currently require restoration due to a lot of damage both in structure and architecture in order to ensure they regain their original shape and condition. It has, however, been reported that the restoration and renovation of existing buildings are more complex than building new ones (Efthimiadou et al., 2017; Kareeva & Glazkova, 2017). Nevertheless, efforts are required to restore buildings with historical value to maintain their honour and contribution to history (Rosas, 2005). The process is expected to be established on the standards or regulations applied in the conservation of cultural and historical monuments (Murgul, 2015). Inong Balee Fort is the evidence indicating the glory of the Aceh Islamic Kingdom in the 16th century. It is located in Lamreh Village, Masjid Raya Sub-District, Aceh Besar District facing the Indian Ocean as shown in the map of Figure 1.



Figure 1. The map of Inong Balee Fort location
Source: Government of Aceh Besar District

The fort was built in 1599 by the first female admiral in the world, Admiral Malahayati, during the Sultanate of Alauddin Ri'ayat Syah Sayyidil Mukammil (Passchier et al., 2012). It was the centre of military logistics for the Aceh Kingdom at the time and the place of training for royal female soldiers

known as Inong Balee Fleet and reported to initially consist of 1000 widows of war casualties but later strengthened with teenage girls to increase the number to 2000. The fleet was involved in a battle against Dutch colonialism and succeeded in defeating two brothers which led the Dutch trading fleet including Cornelis deHoutman that was killed and Frederick de Houtman caught and imprisoned for 2 years (Saifullah, 2012). This means Inong Balee Fort has a high historical value to the country, therefore, the Indonesian Government makes it one of the protected cultural heritage sites.

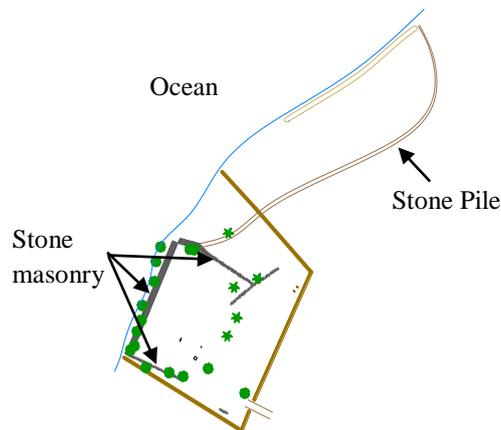


Figure 2. Plan of Inong Balee Fortress

Source: On-site observations and measurements

The main part of the fort is made of stone masonry with a thickness of 2 m and a height of 2.5 m while the northwest aspect only has a stone structure as shown in Figure 2. According to estimates by the Medan Archeological Agency, the structure of the stone pairs is rectangular with a size of 60 m x 40 m while Hermansyah & Nasruddin (2013) showed the main raw materials for the fort consisted of river and mountain stones glued together with a mixture of limestone, clay, and sand as observed in other forts in Aceh built at the same time. Meanwhile, the adhesive was obtained by burning lime and shellfish.

The fort currently only has walls on the north and west sides (Hermansyah & Nasruddin, 2013) while several parts of the masonry wall have been damaged and the stone has fallen from the mortar bonds (BPCB/Institute for Preservation of Cultural Heritage of Aceh, 2016) as shown in Figure 3. The importance of this fort to the county in terms of archaeology, history, science, and education has made the Indonesian Government through the Institute for Preservation of Cultural Heritage of Aceh to plan a restoration process. Meanwhile, Indonesian Law no. 11/2010 Article 77 states that the restoration of cultural heritage has to pay attention to the authenticity of the material, shape, layout, style, and workmanship technology. Therefore, it is necessary to know the characteristics of the binding mortar used during the fort construction in order to design a new

binding mortar with similar characteristics for restoration. Several studies have recently been conducted on binding mortar for masonry (Amin, 2012; Reddy et al., 2013; Hossain et al., 2016; Khan et al., 2017; Slivinskas et al., 2017; Venkatesh et al., 2017; Nahbab & Zahra, 2018; Hasan et al., 2020a, b; Saidi et al., 2020; Saidi & Hasan, 2020; Marvila et al., 2020 and Shah et al., 2020) but none focused on the mortar to restore historical buildings. Moreover, previous studies showed the difficulty in the process of these buildings' restoration (Kareeva & Glazkova, 2017), the need to consider the characteristics and performance of the building structure (Efthimiadou et al., 2017), and their architecture (Rosas, 2005).

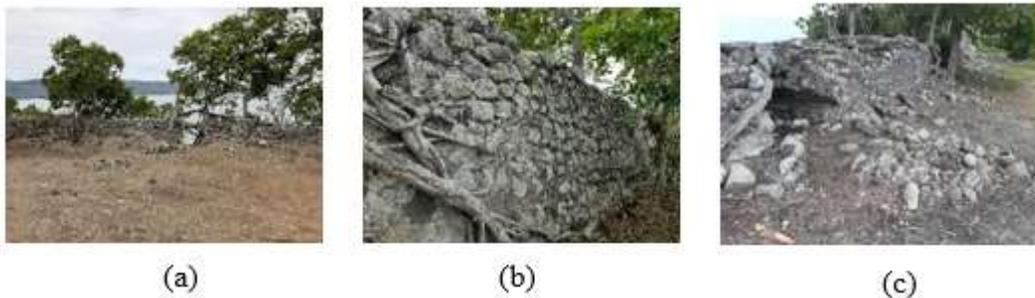


Figure 3. The current condition of Inong Balee Fort: (a) The west side wall; (b) Sea side wall; (c) The stones that had fallen from the fort walls

Source: Authors documentation

This research was, therefore, conducted to determine the binding mortar characteristics including the chemical compounds and minerals used in the Inong Balee Fort. This was followed by the design of a new mortar for restoration with almost the same characteristics as the mortar in the Inong Balee Fort. Moreover, the similarity of the materials with the original was observed and the mortar for restoration was discovered to need a strong structure, therefore, the compressive strength was determined and confirmed to meet the requirements of the binding mortar according to National Indonesian Standards SNI 6882:2014 and ASTM C270-19a Standards.

Research methods

Mortar Characterization of Inong Balee Fortress

The first step in the research was obtaining mortar samples from the intact and undamaged structure of the Inong Balee Fort to ensure they are not contaminated with soil or other substances with possible effects on the content. The samples were further broken into small chunks, pounded to ensure they are smooth, and sieved using a sieve no. 200 which is 0.075mm in size.

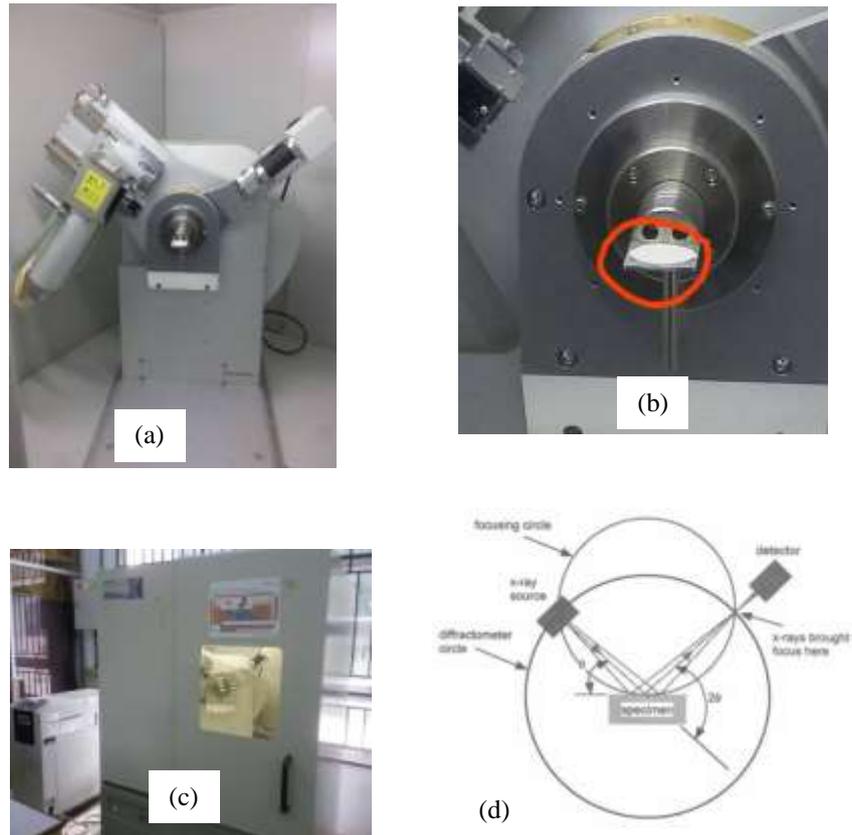


Figure 4. XRD test on samples: (a) setting of XRD devices (b) placement of the sample powder on the peak (c) sample characterization process (d) the working principle of XRD devices

The sieved powder samples were characterized using the X-Ray Diffraction (XRD) test through the use of a Maxima XRD-7000 device made by SHIMADZU as shown in Figure 4. The XRD device uses X-ray radiation from XRD pipes with wavelengths of 0.154184. This test was used to obtain the information on the crystal structure of the material (Suharyana, 2012) with the diffraction pattern produced observed to be in the form of diffracted X-ray diffraction intensity and angles of 2θ . Moreover, each pattern in the XRD represents a crystal plane with a certain orientation (Widyawati, 2012), and test results were further analyzed by matching them with the angle value obtained from the Joint Committee on Powder Diffraction Standards (JCPDS) database.

Mortar Design for Restoration Purposes

The materials used to design the mortar for restoration purposes are lime, cement, and sand. The lime was obtained by burning limestone (CaCO_3) in a furnace at a temperature of 1100°C while the cement was Portland Pozzolana Cement by PT Semen Andalas Indonesia with a specific gravity of 3.16. The sand has a maximum grain size of 4.75 mm and examined for its physical properties and grain grading before use with the results shown in Table 1 and Figure 5

respectively. The sand was discovered to have met the aggregate requirements for mortar-forming materials as required in ASTM C144-18 as shown in Table 1.

Table 1. Physical properties of sand

| Physical properties | Test Results | ASTM C144-18 Requirements |
|----------------------|--------------|---------------------------|
| Density(kg/ltr) | 1.492 | > 1.2 |
| Specific gravity SSD | 2.433 | 2.0 – 2.7 |
| Specific gravity OD | 2.374 | 2.0 – 2.7 |
| Absorption(%) | 2.521 | 0 – 5 |
| Fineness modulus | 2.362 | 1.5 – 3.8 |

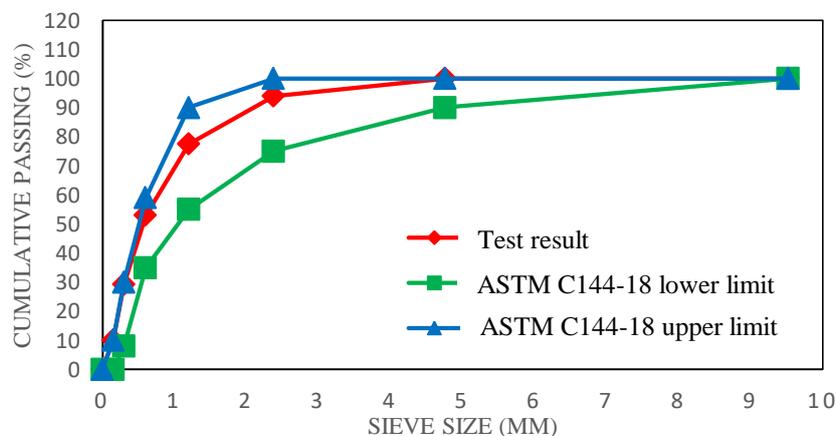


Figure 5. Gradation of sand grains
Source: Test result

Two mortar mixtures were designed using the basic ingredients of cement, lime, and sand for restoration purposes, and the material proportions were based on the volume ratio as presented in Table 2. Moreover, the mortar was produced by mixing and stirring all the materials in a mixer after which water was added up to 48.4% of the cement and lime total weight and evenly mixed according to ASTM C109/C109M-20b Standard. The 50 mm cube specimens were made in 5 moulds provided for each mortar mixture and the specimens were removed from the mould after one day and later cured in water. Furthermore, the compressive strength was determined by applying a load through the Universal Testing Machine (UTM) to the specimens aged 28 days until it is crushed based on the SNI 03-6825-2002 and ASTM C109 / C109M-20b Standards as shown in Figure 6. Meanwhile, the two mortar mixtures were tested using the XRD with the same method as the samples obtained from the fort.

Table 2. Mortar Design for Restoration Purposes

| Mixture | Volume Ratio | | |
|---------|--------------|------|------|
| | Cement | Lime | Sand |
| A | - | 1 | 2 |
| B | 1 | 2 | 3 |



Figure 6. Compressive strength test for the mortar samples
Source: Author Documentation

Results and Discussion

Characteristics of Inong Balee Fortress Mortar

The XRD test results showing the pattern of the mortar sample in Inong Balee Fort are presented in Figure 7 and the highest peak was observed at an angle of 2θ of 29.410. This means the dominant compound in the fort mortar is CaCO_3 in the form of calcite limestone and the binding mortar was made of lime. The next peak was recorded at an angle of 2θ of 26.508 and this indicates the SiO_2 compound or silica is also dominant while the other compounds are P_2O_5 , MgCO_3 , and Al_2O_3 . Therefore, the mortar of Inong Balee Fort was confirmed to be made of lime and sand.

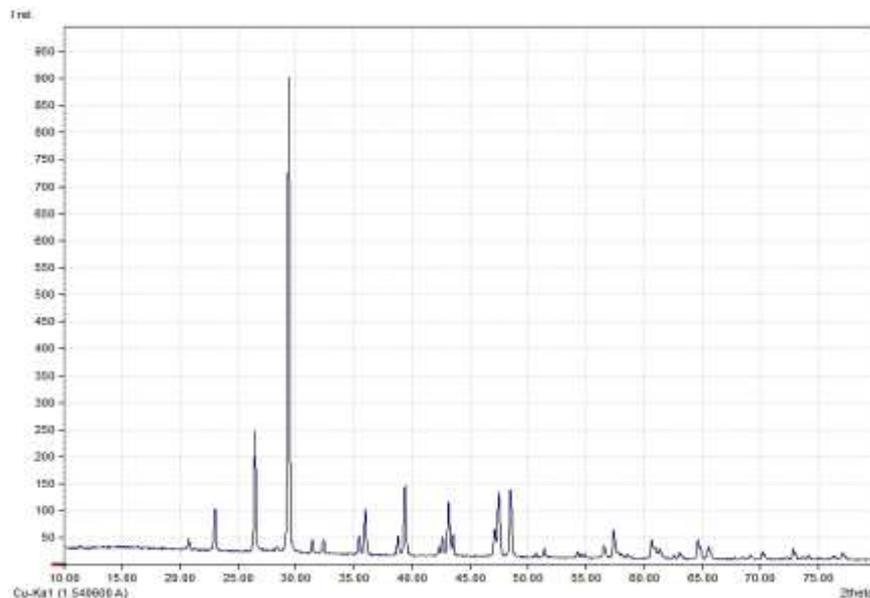


Figure 7. X-ray diffraction pattern of mortar in Inong Balee Fort

Source: Test Result

Compressive Strength and Characteristic of Mortar for Restoration Purposes

The average compressive strengths of mortar mixtures A and B designed for restoration purposes and those required by SNI 6882:2014 and ASTM C270-19a Standard are presented in Table 3. The data show mixture A does not meet the requirements for masonry mortars while B is included in the type O mortar group which are can be used for exterior or interior masonry wall which are not carrying heavy loads. This, therefore, means it is possible to use mixture B for the restoration of Inong Balee Fort in terms of strength.

Table 3. Mortar compressive strength

| Mortar | Experiment | | SNI 6882:2014 and ASTM C270-19a | | | |
|----------------------------|------------|------|---------------------------------|--------|--------|--------|
| | A | B | Type M | Type S | Type N | Type O |
| Compressive Strength (MPa) | 1.41 | 2.45 | > 17.2 | > 12.4 | > 5.2 | > 2.4 |

The X-ray diffraction pattern of A mixture mortar from the XRD test is presented in Figure 8 and was observed to be almost similar to those in the mortar of Inong Balee Fort. The compounds found in the mixture include CaCO_3 , CaO , SiO_2 , Al_2O_3 , Fe_2O_3 , MgCO_3 , $\text{MgCa}(\text{CO}_3)_2$, and P_2O_5 and this means it contains all the compounds contained in the Inong Balee Fort mortar. However, three additional compounds including CaO , Al_2O_3 , and $\text{MgCa}(\text{CO}_3)_2$ were also found in the mixture.

The X-ray diffraction pattern of B mixture mortar based on the XRD test is presented in Figure 9 and was found to also be almost similar to those in Inong Balee Fort and A mixture mortars. The compounds discovered in the B mixture mortar are CaCO_3 , CaO , SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , MgCO_3 , $\text{MgCa}(\text{CO}_3)_2$, and

P₂O₅ and this means it has all those observed in A mixture and Inong Balee Fort mortars. However, B mixture mortar has another compound discovered not to be in A mixture mortar which is MgO, and several others not in Inong Balee Fort such as CaO, Al₂O₃, MgO, and MgCa(CO₃)₂.

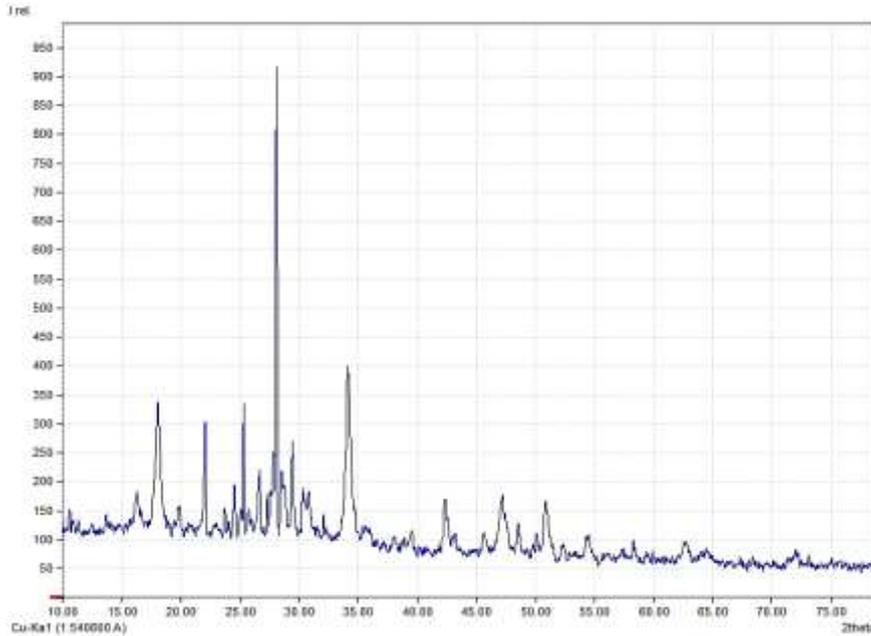


Figure 8. X-ray diffraction pattern of A mixture mortar
Source: Test Result

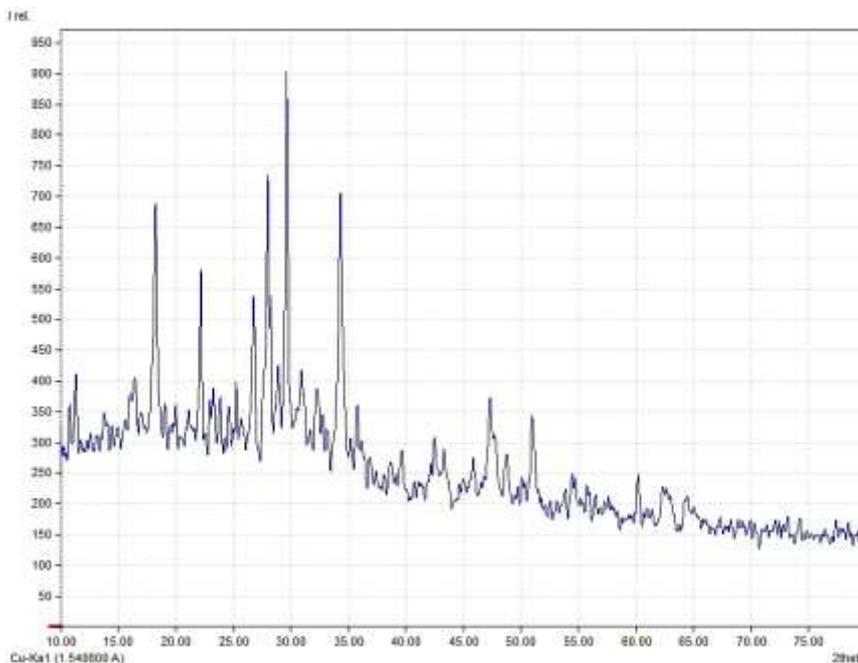


Figure 9. X-ray diffraction pattern of B mixture mortar
Source: Test Result

Conclusion

This research was conducted on the binding mortar of Inong Balee Fort and the specimens designed for restoration purposes. It was discovered that the main compounds in the binding mortar of Inong Balee Fort are CaCO_3 and SiO_2 with the main mineral being calcite while some others observed include P_2O_5 , MgCO_3 , and Al_2O_3 . Therefore, the binding mortar for the fort was made of lime and sand.

The main compound in the mortar with a mixture of 1 lime: 2 sand was found to be CaCO_3 and SiO_2 which is the same with Inong Balee Fort while others found in this specimen include CaO , Al_2O_3 , Fe_2O_3 , MgCO_3 , $\text{MgCa}(\text{CO}_3)_2$, and P_2O_5 . The mixture also has a compressive strength of 1.41 MPa and this is considered lower than the values required by SNI 6882: 2014 and ASTM C270-19a Standards which means it cannot be used for the masonry binding mortar. Meanwhile, the major compound in the mortar with a mixture of 1 cement: 2 lime: 3 sand was also CaCO_3 and SiO_2 which is similar to those observed in Inong Balee Fort while the others include CaO , Al_2O_3 , Fe_2O_3 , MgO , MgCO_3 , $\text{MgCa}(\text{CO}_3)_2$, and P_2O_5 . The compressive strength of the mixture was 2.45 MPa and this means it is a type O mortar group based on SNI 6882: 2014 and ASTM C270-19a Standards and applicable in interior and exterior wall binding mortars which do not carry heavy loads. Therefore, this mixture is usable in restoring the Inong Balee Fort as well as to preserve it for the future due to its strong structure.

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