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COMPOSITION AND CHARACTERISTICS OF BRICK FOR CONSERVATION AND RESTORATION MATERIALS OF HERITAGE BUILDINGS AS AN INSPIRATION FOR SUSTAINABLE CONSTRUCTION

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Abstract

To realize sustainable Cultural Heritage buildings and preserve cultural heritage, an appropriate concept of cultural heritage restoration and material appropriate to their function are needed. One of which is brick material for heritage buildings. Current bricks are different from heritage/old bricks, visually evident through their shape and colour. Heritage bricks must *be studied to find their characteristics and composition so they can be used as cultural heritage restoration materials in the world. The composition and characteristics of heritage bricks have been studied and the results show that the physical and mechanical properties of heritage bricks vary. Therefore, research is needed on the development of renewable/repair heritage bricks as materials in the restoration of cultural heritage buildings, by identifying the characteristics and composition of renewable bricks. The methods applied include experiments and testing in the field and laboratory. The characteristics of renewable bricks in terms of physical strength have been designed with a size of 5.5x14x25.5 without shrinkage because they come from selected clay, have flat surfaces, sharp corners, and colours similar to heritage bricks. Tests were also conducted on the mechanical properties, such as water absorption, apparent density, and compressive strength, of all heritage bricks, and the best values for use as renewable materials were obtained.*

Keywords:

Renewable Heritage Bricks, Repair Brick, Cultural Heritage, Composition, Characteristics, Material

1. Introduction

Heritage buildings are buildings that have national historical and cultural value that are important for the understanding and development of science and culture in the world, so they need to be preserved and managed properly. Cultural heritage buildings are Heritage Buildings that have gone through a designation process. Therefore, not all Heritage Buildings are cultural heritage. In maintaining cultural heritage, the state has the responsibility to protect, develop, and utilize it, therefore, for example in Indonesia, the Republic of Indonesia Law No. 11 of 2010 concerning cultural heritage was issued. In a quote from the UNESCO World Heritage Center it is stated that "Heritage is our legacy from the past, what we enjoy today, and what we leave to future generations. Our cultural and natural heritage is an irreplaceable source of life and inspiration," confirming that Cultural Heritage Buildings are cultural heritage that needs to be preserved. Current issues faced regarding cultural heritage are the limited number of cultural heritage conservation experts, damage to Cultural Heritage Buildings, and the lack of understanding of owners and the community about cultural heritage and the value of Cultural Heritage Building assets, which are the main challenges in preservation efforts. Therefore, efforts are needed to inspire sustainable development in Indonesia's cultural heritage so that Cultural Heritage Buildings can benefit the world.

The Indonesian Environmental Protection Agency, for example, defines sustainable construction as "the practice of constructing structures and processes that are environmentally responsible and efficient in the use of resources throughout the building's life cycle, from siting, design, construction, operation, maintenance, renovation, and deconstruction." The concept of sustainability takes into account environmental sustainability and the practices that influence it.

To achieve sustainable development of Cultural Heritage and preserve cultural heritage, an appropriate restoration concept is required. Therefore, restoration materials appropriate to their role are needed, one of which is brick for heritage buildings. Today's brick is very different from the brick of the Dutch era, as is evident in its shape and color. The composition of brick has been studied by Hana W. Puruhita (2025), who discovered the characteristics and composition of Dutch-era brick, which can serve as a reference in the development of restoration materials for cultural heritage sites worldwide. Therefore, a method is needed to identify the physical and mechanical characteristics of the bricks material. For further study, a more comprehensive study of bricks, including the distance to the wall and even the building structure, is needed.

Several previous similar studies on bricks have been conducted, but none have examined heritage bricks. Therefore, in-depth research is needed to determine the potential for renewable heritage bricks as a material for the restoration of cultural sites. Research by Basak Zengin (2017) revealed that wall damage is influenced by the materials used, installation methods, and the bonding between brick units and joints. The study identified the direction of the voids in fabricated and renewable bricks, which align with heritage wall masonry, necessitating the need for lime mortar as a connecting link. A study by Bayu and Teguh (2024) found that the water absorption capacity test results for one heritage building were 24.4%, thus still categorized as good quality, as it did not exceed 30%. This research aims to examine the characteristics of heritage/Dutch-era bricks; analyze the composition of heritage/Dutch-era bricks; and determine the physical and mechanical properties for manufacturing bricks as a repair material for the restoration of cultural sites.

2. Research Methods

1. Renewable bricks are made from the best materials from various cities in Indonesia, particularly Central Java and East Java, with a minimum of 8 locations, including clay and lime.
2. Renewable bricks production is carried out at one of Indonesia's bricks production facilities to ensure complete equipment and support by experienced personnel.
3. Laboratory research locations: Bricks Characteristics Test: Laboratory of the Faculty of Civil Engineering, Sebelas Maret University, Surakarta, Indonesia; Bricks Composition Test: Integrated Laboratory, Sebelas Maret University, Surakarta, Indonesia.
4. Research tools: The tools used are a square ruler, calipers, a compressive strength machine, and a practical tool for mathematics and natural sciences materials.
5. Research type and design: laboratory test, experiment.
6. Research variables: heating temperature (dependent variable), heating time (dependent variable), bricks composition (independent variable).
7. Research Procedure:
    a. Physical property testing, conducted through visual inspection and measuring tools.
        1) Shape testing, conducted through visual inspection of the shape, angles, and corners.
        2) Appearance testing of bricks, in accordance with Indonesian National Standard (SNI) 15-2094-2000, as a requirement and testing procedure, requires the bricks to be rectangular prism-shaped, have right-angled edges, flat surfaces, and no cracks. A square tool is used to determine the flat surfaces and right-angled edges. Length, width, and thickness measurements are taken at least three times using calipers or similar tools with an accuracy of 1 mm. The maximum deviation from the length, width, and

thickness of each brick is determined, expressed in mm. c) Dimensional/measurement testing is conducted using a ruler/meter to determine the length, width, and height.

b. Mechanical property testing is conducted to determine the properties that indicate the material's behavior when subjected to mechanical loads (static or dynamic) according to the American Society for Testing and Materials (ASTM) C67.
   1) Compressive strength testing (minimum 50 kg/cm2): in accordance with SNI 03-4164-1996, namely the Laboratory Method for Testing the Compressive Strength of Brick Walls. Water absorption test (maximum 20%): SNI 15 2094 2000 Bricks for Walls
   2) Apparent Density test (minimum 1.2 grams/cm3): SNI 15 2094 2000 Bricks for Walls
   3) Salt content test (best if the MgSO4, Na2SO4, and K2SO4 content is a maximum of 1%) using the XRF composition test results: SNI 15 2094 2000 Bricks for Walls
   4) XRF (X-Ray Fluorescence) testing is an analytical method for quickly determining the elemental composition of a material/sample. The principle used in determining elements is based on the interaction of X-rays with the material/sample.

8. Data analysis techniques: Heritage bricks that have been lab-tested for compressive strength, water absorption, salt content, and physical form are used as a reference in the experimental process of producing renewable bricks.

3. Result

Characteristics of Repair bricks

1. Reference Data for Repair bricks

   The characteristics of repair bricks refer to the physical and mechanical properties of the heritage bricks material studied, namely:

   a. Physical properties: shape, dimensions, surface, angularity, angularity, and color appearance.

   b. Mechanical properties: Apparent Density Test, Water Absorption Test, and Compressive Strength Test.

2. Physical Properties of Repair bricks

   The characteristics of the repair bricks to be made are based on the conclusions regarding the physical properties of heritage bricks, namely:

   a. Shape: rectangular cube

   b. Dimensions: Dimensions vary for each building and region/area (average dimensions are 5.5 x 14 x 25.5 cm).

   c. Surface: flat

d. Angularity: 90° angle
e. Angular angularity: sharp
f. Appearance color: average of numbers 2 and 5.
g. Conduct a pilot test by taking into account the additional dimensions during the manufacture of the solid bricks mold, then calculate the shrinkage.

3. Mechanical Properties

The characteristics of the repair bricks to be manufactured are based on the conclusions regarding the mechanical properties of heritage bricks, namely:

a. Apparent density: The highest value is 2.624 and the lowest is 1.333 grams/cm3 (the minimum standard is 1.2 grams/cm3).
b. Water absorption: The minimum value is 14% and the maximum is 27% (the maximum standard value is 20%).
c. Compressive strength: The maximum value is 69.11% and the minimum is 32.35%. (The standard value is > 50 kg/cm2).

4. Repair bricks manufacturing method (process of manufacturing):

a. Raw materials:
   1) Pure clay (fine, not mixed with sand, gravel, or organic materials), taken from several different regions.
   2) Clean water
b. Material Processing
   1) Soak the clay in clean water for several days, around 2-7 days, to make it plastic and easy to shape.
   2) Knead the clay (tread on it) until there are no lumps.
   3) Ensure the clay is homogeneous.
c. Molding the Materials
   1) Make a wooden mold measuring 5.5 x 14 x 25.5 cm.

Figure 1: *Wooden mold measuring 5.5 x 14 x 25.5 cm*

2) The size of the wooden brick mold can be adjusted according to needs.
3) Pouring the processed clay into the wooden mold.

d. Drying the Material
1) The wet repair brick mold is dried in a shaded area (not exposed to direct sunlight) for 1-2 weeks.
2) Drying is done naturally to prevent cracking during the firing process.

e. Firing
1) The bricks are arranged in a clay kiln.
2) They are arranged neatly and tightly, but with gaps to allow heat to flow.
3) Using firewood, charcoal, or rice husks as fuel.
4) The firing process takes approximately 2 weeks with a gradual fire (period 1: temperature 200-400°C, period II: temperature 401-800°C, period III: temperature 801-950°C), then the fire is allowed to die down.
5) The bricks are cooled naturally for 2-3 days before being removed from the kiln.

f. Final results
1) The bricks are dense and hard
2) The bricks are heavier than modern bricks

5. Results of repair bricks production
a. Locations for selecting clay samples
1) Karangmalang District, Sragen Regency
2) Masaran District, Sragen Regency
3) Mojolaban District, Sukoharjo Regency
4) Barat District, Magetan Regency
5) Jiwan District, Madiun Regency
6) Laweyan District, Surakarta City
7) Jaten District, Karanganyar Regency
8) Kedunggalar District, Ngawi Regency

b. Results of bricks from different locations/regions

Figure 2: *Repair bricks Production Results*

Physical Properties

The characteristics of the repair bricks in eight samples were determined using physical properties tests, specifically physical appearance. The physical appearance test was conducted using calipers, a protractor, a triangle ruler, a long ruler, and a hand tape measure. The color appearance test was reviewed using the website link: https://www.true-design-house.com/blog/earthy-brick-paint-combinations, so the color numbering options can be seen in Figure 1. Renewed bricks at each location have different colors due to differences in materials, even though they are made using the same manufacturing process and method. Testing was conducted by observing the color appearance of the inner side of the bricks. The results of the test of the characteristics of the renewed bricks in eight samples, conducted using the physical appearance test, are shown in Table 2. The method for testing the appearance of bricks in accordance with SNI 15-2094-2000, namely, they must be rectangular prism-shaped, have right-angled edges, have flat surfaces, and show no cracks. To find out the angles, use a protractor and a triangle ruler. The right angle is said to be sharp if the results of the X and Y coordinate values are close to 90º, not less than 80º, and the sharpness of the angle is considered sharp if the magnitude of the X, Y, and X coordinates is close to 90º, not less than 80º. To find out the flat planes, as well as the right angles of the ribs, use a right angle tool. According to SNI 15-2094-2000, each measurement of length, width and thickness is carried out at least 3 times using a long ruler, meter, and calipers or similar tools with an accuracy of up to 1 mm.

From the results of the measurements of the length, width, and thickness of each brick, the maximum deviation is determined and expressed in mm.

Figure 3: *Color numbering on bricks material*

Table 3.1 *Results of Physical Characteristics Test of Repair bricks Samples*

No	Sample	Shape	Dimension	Surface	Angle	Sharpness	Colour
1	Brick 1	Rectangular Cube	5,5x13x23,5cm	Flat	elbow 90°	Sharp	No.1
2	Brick 2	Rectangular Cube	5x12,5x22,5cm	Flat	elbow 90°	Sharp	No. 5
3	Brick 3	Rectangular Cube	5x12,5x23cm	Flat	elbow 90°	Sharp	No. 8
4	Brick 4	Rectangular Cube	5,5x13,5x24cm	Flat	elbow 90°	Sharp	No. 8
5	Brick 5	Rectangular Cube	5,5x13,5x25cm	Flat	elbow 90°	Sharp	No. 8
6	Brick 6	Rectangular Cube	5x12,5x23,5cm	Flat	elbow 90°	Sharp	No. 1
7	Brick 7	Rectangular Cube	5,5x14x25,5cm	Flat	elbow 90°	Sharp	No. 2
8	Brick 8	Rectangular Cube	5x13x24cm	Flat	elbow 90°	Sharp	No. 2

Based on the visible test results, it can be concluded that from the test of the characteristics of repair bricks in terms of physical properties, all repair bricks are rectangular cube-shaped, with different dimensions even though the materials are in the same region or from different regions. The dimensions of the repair bricks vary, but there are 1 brick whose dimensions match the wooden mold, which is 5.5 x 14 x 25.5 cm, namely brick number 7. All surfaces are flat, 90^o angles, and sharp corners. Repair bricks have different colors. In the tested bricks, 100% intake meets the visible properties test according to SNI 15-2094-2000. The results of the bricks size test do not meet SNI 15-2094-2000, due to differences in size/dimensions in heritage bricks and there is a shrinkage value seeing the age of heritage bricks. Brick number 7 is a brick made from clay in the Jaten Karanganyar area with clay conditions that have been left for a long time, namely more than 1 year. Making repair bricks with the same material specifications as number 7 does not require additional dimensions to the mold, because there is no shrinkage in size in the resulting repair bricks.

Mechanical Properties

The characteristics of heritage bricks in 10 samples were determined using mechanical properties tests, including the results of tests conducted in the Civil Engineering Laboratory, including Apparent Density Test, Water Absorption Test, and Compressive Strength Test (ASTM E447-97.1997). The results of the heritage brick's mechanical properties were taken from three samples at each location, as shown in Tables 3, 4, and 5. According to SNI 15-2094-2000, the procedure for testing the compressive strength of solid bricks is as follows: after molding, the test specimens are removed the next day. They are then soaked in clean water (room temperature) for 24 hours (one day). They are then removed and their surfaces wiped with a damp cloth to remove excess water. The specimens are then compressed until they break, with a compression rate set to 2 kg/cm2/second. The compressive strength value is obtained by dividing the highest compressive load by the smallest compressive area. The average compressive strength is obtained by dividing the sum of the compressive strengths of all specimens by the number of specimens. According to SNI 15-2094-2000 the water absorption test procedure is: The test sample is soaked in water until saturated, then weighed (A). Dried at a temperature of (100-110)^{o}C for 24 hours, after which it is cooled to room temperature and then weighed (B). Finally, it is calculated using the formula (A-B) / B x 100%, so that the water absorption value is obtained. Test documentation is in figures 4 to 6.

Figure 4: *Apparent Density Test Sample*

Figure 5: *Water Absorption Test Sample*

Figure 6: *Compressive Strength Test Sample*

Bricks samples were taken from 10 different locations, each with a minimum of three bricks. This refers to Roscoe in Sekaran (2000), who stated that in determining sample size, it is important to consider guidelines. For simple experimental research with strict experimental control, a good sample size can be used with a sample size of approximately 10 to 20. Statistical tests were not performed in this study because the research method used was experimental. Experimental research analysis aims to test the effect of the treatment (independent variable) on the outcome (dependent variable) under strict control, so that differences in results can be directly attributed to the treatment. Research Objective: Experimental research is designed to test hypotheses about the causal relationship between the independent and dependent variables. Experimental research emphasizes strict control of other variables that may influence the results, so that observed differences in results can be attributed to the treatment.

Table 3.2 *Results of Mechanical Property Characteristic Tests (Apparent Density) of Heritage Bricks Samples*

No	Sample	Length (mm)	Width (mm)	Height (mm)	Oven dry weight (grams)	Weight in water (grams)	SSD weight (grams)	Apparent density (gr/cm3)
1	Brick 1.1	5,12	5,17	5,93	230,4	261	409,10	2,606239
2	Brick 1.2	4,98	5,98	5,27	234,2	270,5	407,5	2,596489
3	Brick 1.3	5,98	4,87	5,22	281,4	200,4	404,8	2,662808
4	Brick 2.1	5,45	5,12	5,73	267,6	158	343,30	2,147102
5	Brick 2.2	4,76	5,72	5,44	261,3	161,3	325,4	2,196927
6	Brick 2.3	4,67	5,86	5,12	239,5	146,3	308,8	2,203905
7	Brick 3.1	5,99	4,76	5,29	263,6	153,8	335,10	2,221698
8	Brick 3.2	5,81	4,87	4,69	282,2	121,1	306,1	2,30667

No	**Sample**	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Oven dry weight (grams)**	**Weight in water (grams)**	**SSD weight (grams)**	**Apparent density (gr/cm3)**
9	Brick 3.3	5,23	5,54	5,29	290	138,6	351,6	2,293938
10	Brick 4.1	5,09	5,01	5,37	184,6	138,4	240,70	1,757706
11	Brick 4.2	5,56	5,27	5,61	274,6	124,5	301,9	1,836601
12	Brick 4.3	5,76	4,98	5,30	195,5	165,3	283,8	1,866744
13	Brick 5.1	5,54	5,86	5,23	251,5	154,3	323,50	1,905308
14	Brick 5.2	5,23	5,18	5,84	271,2	134,6	308,6	1,950525
15	Brick 5.3	5,12	5,26	5,27	225,4	125,4	273,8	1,929155
16	Brick 6.1	4,75	5,15	5,39	282,2	127,4	327,30	2,482312
17	Brick 6.2	5,57	4,99	5,38	265,3	192,5	360,6	2,411502
18	Brick 6.3	5,46	5,06	5,76	262,1	194,4	379,5	2,384768
19	Brick 7.1	5,44	5,18	5,93	284,5	282,5	484,70	2,900612
20	Brick 7.2	5,29	5,45	5,38	333,4	208,9	445,1	2,869612
21	Brick 7.3	5,16	5,63	5,45	294,5	252,3	469,8	2,967279
22	Brick 8.1	4,86	4,68	5,23	261,4	132,3	311,40	2,61779
23	Brick 8.2	5,86	5,22	5,02	363,3	138,5	404,6	2,634839
24	Brick 8.3	5,23	5,11	5,50	310,3	155,5	388,8	2,645093

The apparent density test results for all heritage bricks samples meet the requirements of SNI 15-2094-2000, which is a minimum of 1.2 grams/cm3. The highest value was 2,967279 and the lowest was 1,757706 grams/cm3.

Table 3.3 *Results of the Mechanical Properties (Water Absorption) Test of Heritage Bricks Samples*

No	Sample	SSD Weight (grams)	Oven Dry Weight (Grams)	Water absorption (%)
1	Brick 1.1	1116,8	998,2	12%
2	Brick 1.2	1076,8	957,2	12%
3	Brick 1.3	1098,9	982,4	12%
4	Brick 2.1	986,3	850,5	16%
5	Brick 2.2	575,3	497,4	16%
6	Brick 2.3	746,6	644,5	16%
7	Brick 3.1	876,9	776,8	13%
8	Brick 3.2	557,7	497,8	12%
9	Brick 3.3	1024,5	910,4	13%
10	Brick 4.1	517,9	429,3	21%
11	Brick 4.2	562,3	462	22%
12	Brick 4.3	524,2	434,3	21%
13	Brick 5.1	1098,2	924,5	19%
14	Brick 5.2	1143,2	958,8	19%
15	Brick 5.3	1235,9	1045,1	18%
16	Brick 6.1	769,7	678,9	13%
17	Brick 6.2	875,5	774,9	13%
18	Brick 6.3	709,5	629,3	13%
19	Brick 7.1	1521,2	1387,9	10%
20	Brick 7.2	1624,9	1477,7	10%
21	Brick 7.3	1498	1365,1	10%
22	Brick 8.1	1098,1	978	12%

No	Sample	SSD Weight (grams)	Oven Dry Weight (Grams)	Water absorption (%)
23	Brick 8.2	1003,2	897,2	12%
24	Brick 8.3	987,9	882,4	12%

The results of the water absorption test on Heritage Bricks 3 out of 10 sampling locations meet the requirements of SNI 15-2094-2000, with a maximum value of 20%. The minimum value is 10% and the maximum is 22%.

Table 3.4 *Results of Mechanical Properties Characteristics Test (Compressive Strength) of Heritage Bricks Samples*

No	Sample	Length (cm)	Width (cm)	Height (cm)	Load (kN)	Load (kg)	Compressive strength (kg/cm2)
1	Brick 1.1	11,212	12,621	13,452	100	10197	72,06021665
2	Brick 1.2	11,231	11,857	12,105	95	9687,15	72,7449379
3	Brick 1.3	12,096	11,665	13,486	100	10197	72,26797706
4	Brick 2.1	11,898	12,761	13,207	100	10197	67,16047299
5	Brick 2.2	12,247	11,736	12,554	95	9687,15	67,39787533
6	Brick 2.3	11,963	12,557	11,836	100	10197	67,88071721
7	Brick 3.1	13,339	12,331	14,006	110	11216,7	68,19358686
8	Brick 3.2	12,773	12,736	13,735	110	11216,7	68,9507734
9	Brick 3.3	13,474	12,765	13,009	115	11726,55	68,17935644
10	Brick 4.1	14,152	9,043	14,747	50	5098,5	39,8393343
11	Brick 4.2	12,238	12,754	14,998	60	6118,2	39,19826171
12	Brick 4.3	11,886	11,948	13,847	55	5608,35	39,49154903
13	Brick 5.1	13,974	12,659	15,529	95	9687,15	54,76156938
14	Brick 5.2	13,287	12,635	13,776	90	9177,3	54,66542734

No	Sample	Length (cm)	Width (cm)	Height (cm)	Load (kN)	Load (kg)	Compressive strength (kg/cm2)
15	Brick 5.3	13,098	13,501	13,984	95	9687,15	54,78038766
16	Brick 6.1	13,18	9,061	13,702	80	8157,6	68,30788925
17	Brick 6.2	11,089	11,411	14,746	85	8667,45	68,4975844
18	Brick 6.3	10,792	11,052	13,997	80	8157,6	68,3942503
19	Brick 7.1	13,943	12,743	15,887	150	15295,5	86,08664207
20	Brick 7.2	13,592	12,976	14,756	150	15295,5	86,72403492
21	Brick 7.3	13,067	13,976	14,019	155	15805,35	86,54566801
22	Brick 8.1	13,811	10,253	14,331	100	10197	72,0105846
23	Brick 8.2	12,468	11,771	13,878	105	10706,85	72,9544126
24	Brick 8.3	12,687	11,712	14,987	105	10706,85	72,05625967

The compressive strength test results for repair bricks showed 100% of the value, which meets the requirements of SNI 15-2094-2000, with a value of >50 kg/cm2.

Based on the test results, it can be concluded that the mechanical properties of repair bricks, namely water absorption, apparent density, and compressive strength, show that all repair bricks have varying values, even within the same area. The highest apparent density was 2,967279 grams/cm3 for brick 7; the lowest water absorption was 10% for bricks 7. The highest compressive strength was 86,72403492 kg/cm2 for bricks 7.

Repair Bricks Composition

The composition of eight repair brick samples was determined using X-Ray Fluorescence (XRF) testing, which was carried out according to procedures to determine the composition of the elements and compounds present. The testing method and equipment settings were the same as those described in the heritage bricks composition testing section. The results of the XRF testing of ten repair bricks samples are shown in Tables 5a and 5b. The samples used in the XRF were taken from the most optimal assessment results, in accordance with the Indonesian National Standard (SNI), for apparent density, water absorption, and compressive strength at each sampling location: bricks 1, 7, and 8

Table 3.6a *Composition of Dominant Element Content in Heritage Bricks*

No	Name of Element Content	Amount of Element
1	SiO_2 (silikon dioksida/silika)	64,184%
2	Al_2O_3 (aluminium oksida)	18,255%
3	Fe_2O_3 (besi III oksida)	6,772%
4	FeO (besi II oksida)	6,113%
5	CaO (kalsium oksida)	2,693%

Table 3.6b *Composition of Dominant Compound Content in Heritage Bricks*

No	Name of Compound Content	Amount of Compound
1	BAL (bakteri asam laktat)	51,160%
2	Si (silicon)	29,753%
3	Al (aluminium)	9,665%
4	Fe (besi)	4,713%
5	Ca (kalsium)	1,890%

Based on the results of X-Ray Fluorescence (SRF) analysis on 3 samples of renewable bricks, there are several elements and compounds with different content values. The elements contained in them are: TiO2, As2O3, FeO, Ta2O5, Al2O3, NiO, CuO, SiO2, ZnO, MgO, MnO, Fe2O3, ZrO2, CaO, K2O, SrO, P2O5, and Al2O3. These elements are the same as the elements found in heritage bricks. The largest element content in SiO2 (silicon dioxide/silica) with an average value of 64.184%, then the value of Al2O3 (aluminum oxide) is an average of 18.255%, followed by the compound Fe2O3 (iron III oxide) with an average of 6.772%, FeO (iron II oxide) is an average value of 6.113%, the next order is the value of CaO (calcium oxide) with an average value of 2.693%. The compounds contained in heritage bricks material are: Mg, Al, Si, P, K, Ca, Ti, Mn, Fe, Ca, Cu, Zn, As, Rb, Sr, Zr, Ba, Ta, Pb, Se, and BAL. Meanwhile, in heritage bricks there is no Se compound content. The highest content value is BAL (lactic acid bacteria) with an average of 51.160%, then Si (silicon) with an average of 29.753%, followed by Al (aluminum) with an average value of 9.665%, then Fe (iron) with an average of 4.713%, and a smaller content is Ca (calcium) with an average value of 1.890%. The composition table of the elements and compounds from the highest order can be seen in tables 6a and 6b.

4. Conclusion

1. From the results of the heritage bricks characteristics test, in terms of physical properties, all renewable bricks are rectangular in shape, with varying dimensions even within the same area. There are 1 brick with dimensions that match the mold, namely 5.5x14x25.5 made of clay that has been left for at least 1 year, all surfaces are flat, sharp angles, and sharp corners. Renewable bricks have different colors even within the same area with an average of color numbers 1, 2, and 8. In the bricks tested, 100% intake meets the visible property test according to SNI 15-2094-2000. The results of the bricks size test do not meet SNI 15-2094-2000, due to differences in size/dimensions in renewable bricks adjusted to heritage bricks. Therefore, to make renewable bricks, good clay material is needed, namely, left for at least 1 year with characteristics of a whiter color.
2. Based on the results of testing the mechanical properties of renewable bricks, namely water absorption, apparent density, and compressive strength, all renewable bricks have different values, even within the same area. The highest apparent density is brick 7, with an average value of 2.967279 grams/cm3, while the highest water absorption is brick 7 with a value of 10%, and the highest compressive strength is brick 7 with a value of 86.72403492 kg/cm2.
3. The results of the formulation of physical and mechanical properties for making bricks for repair materials as cultural heritage restoration materials can be obtained by looking at the results of physical and mechanical tests with similar values in accordance with cultural heritage law, namely by repairing, strengthening, and/or preserving them through reconstruction, consolidation, rehabilitation, and restoration work that must pay attention to: The authenticity of the material, shape, layout, style, and/or workmanship technology; The original condition with the least possible level of change; and The use of non-destructive techniques, methods, and materials.

Table 3.5a *Results of the Heritage Bricks Sample Composition Test (Element Content)*

No	Brick Name	Element Content (%)																
		TiO_2	As_2O_3	FeO	Ta_2O_5	Al_2O_3	NiO	CuO	SiO_2	ZnO	MgO	MnO	Fe_2O_3	ZrO_2	CaO	K_2O	SrO	P_2O_5
1	Brick1	0,641	0,001	6,134	0,003	18,509	0,000	0,000	63,596	0,012	0,865	0,324	6,821	0,020	2,733	0,933	0,053	0,203
2	Brick 7	0,686	0,001	6,029	0,000	18,082	0,000	0,006	64,473	0,010	0,684	0,175	6,704	0,020	2,646	0,940	0,049	0,185
3	Brick 8	0,656	0,001	6,176	0,000	18,173	0,000	0,000	64,482	0,018	0,712	0,235	6,792	0,038	2,700	0,938	0,057	0,183

Table 3.5b *Results of the Heritage Bricks Sample Composition Test (Compound Content)*

No	Brick Name	Compound Content (%)																			
		Mg	Al	Si	P	K	Ca	Ti	Mn	Fe	Co	Cu	Zn	As	Rb	Sr	Zr	Ba	Ta	Pb	Se	BAL
1	Brick1	0,521	9,798	29,732	0,089	0,774	1,954	0,384	0,251	4,770	0,004	0,000	0.009	0.0008	0.0032	0,045	0,015	0,036	0.0023	0.0035	0,000	50,400
2	Brick 7	0,413	9,572	30,142	0,081	0,780	1,891	0,412	0,135	4,688	0,000	0.004	0,008	0.0004	0.0029	0,042	0,015	0,028	0,000	0.0034	0.0003	51,780
3	Brick 8	0,512	9,624	29,385	0,082	0,778	1,824	0,422	0,189	4,682	0,004	0,000	0,009	0,001	0,003	0,042	0,015	0,031	0,000	0,003	0,000	51,300

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