A Preliminary Assessment of the Potential of Boiler Ash and Spent Bleaching Earth as Raw Materials for Bricks Production

Jennieveb H. Poliran
Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

Jumil M. Pelayo
Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

Jack O. Bertulfo
Department of Agricultural and Biosystems Engineering, College of Engineering and Industrial Technology, Agusan del Sur State College of Agriculture and Technology

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Jennieveb H. Poliran[1], Jumil M. Pelayo[1], Jack O. Bertulfo[2]
[1]Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University, Ampayon, Butuan City, 8600, Philippines
[2]Department of Agricultural and Biosystems Engineering, College of Engineering and Industrial Technology, Agusan del Sur State College of Agriculture and Technology, Bunawan, Agusan del Sur, 8506, Philippines
*Corresponding author email: jobertulfo@asscat.edu.ph

Abstract: *Oil companies generate two byproducts – spent bleaching earth and boiler ash – which pose environmental and operational risks due to their disposal and waste management challenges. This study assesses the potential of Spent Bleaching Earth (SBE) and Boiler Ash for bricks production due to their silica and alumina content. The developed bricks were characterized by their water absorption, compressive tolerance, and flexural strength. A Central Composite Design was used as the experimental design to evaluate the varying levels of SBE and Boiler Ash mixture. The result shows a linear effect on the bricks' compressive strength and flexural strength concerning the amount of SBE, wherein the increasing amount of SBE increased the said properties. Moreover, it was found that the optimum composition for the bricks was 1.8 kg of SBE and 0.6 kg of Boiler ash, which gave the bricks a higher compressive strength and flexural strength. The study provides valuable insights into using Boiler Ash and SBE to develop bricks.*

Keywords: Bricks; boiler ash; spent bleaching earth

1. INTRODUCTION

The recent United States Department of Agriculture (USDA) report shows that the Philippines has exhibited a significant production of approximately 102,000 tons of palm oil within an expansive 66,000 hectares of production area in 2023, resulting in an estimated 1.2 T/Ha yield. In Asia-Pacific, the Philippines is the second-biggest importer of Malaysian palm oil. With 115 million people living in the country, 1.7 million MT of oils and fats were consumed in 2021—a rise of 41,000 MT, or 2.5 percent, from 2020. Despite the escalating palm oil production, a subsequent byproduct stream is generated during the processing of this crop, and one of these byproducts is the spent bleaching earth (SBE).

Spent bleaching earth (SBE) refers to a waste produced by the vegetable oil refining industries. It is estimated globally that 2 million tons of SBE are generated annually, indicating an excess of this waste [1]. The most common method of disposing of SBE is through landfill, which incurs a significant cost and is also environmentally unfriendly. This approach represents an inefficient utilization of SBE, which can potentially be a valuable and useful byproduct. SBE has been considered one of the main problematic hazardous wastes of the food industry [2].

Bleaching earth (BE) and SBE are related but differ in usage and composition. SBE refers to the residual material left after the bleaching process using Bleaching Earth. Once BE is used for oil refining, it becomes "spent" as it becomes saturated with impurities and loses its adsorption capacity [1]. SBE contains the absorbed impurities from the oil, including pigments, trace metals, and other contaminants. SBE is composed of two foremost components: residual oil (about 20–40 wt.%) and montmorillonite clay; thus, every ton of fresh BE used in the refining process produces 1.2–1.6 tons of SBE to be disposed of without treatment or utilization [2]. To reduce the operational costs associated with waste disposal, efforts have been made to regenerate the SBE [3]. BE is a natural clay composed of sepiolite, attapulgite, or montmorillonite mineral, which is a hydrated aluminum silicate [3][4]. The SBE used in this study contains various elements, including SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, and Na_2O [5]. These elements are important in determining the chemical composition and potential reactivity of SBE during the firing process [6][7][8].

An environmentally right arrangement currently being explored is the employment of SBE as a valued absorbent to get rid of contaminants [8] or to be added to construction materials [9]. The SBE can be utilized for brick clay because its chemical composition is like [10] as a clay substitute in the bricks, blocks, or tile manufacturing process [5][6].

Caraga Oil Refining Inc. (CORI) is a sister company of Filipinas Palm Oil Plantation Inc. (FPPI). FPPI, a palm oil production company, generates boiler ash (BA) as a byproduct from the combustion of wood, coconut, and shredded empty fruit bunches (EFB) in their boilers during palm oil extraction.

BA from FPPI consists of inorganic materials, such as unburned wood or EFB residue, ash particles from the combustion of these biomass materials, and any other solid impurities present in the fuel. The composition of BA may vary depending on the type of biomass used, the combustion conditions, and the properties of the boilers. BA from FPPI, generated from the combustion of wood, coconut, and shredded empty fruit bunches (EFB) in boilers, may contain chemical components that can be like those used in producing fired bricks.

According to the study of Yahya et al. [7], BA is typically composed of inorganic materials, including oxides of silica (SiO_2), alumina (Al_2O_2), iron (Fe_2O_3), calcium (CaO), magnesium (MgO), and potassium (K_2O), among others, depending on the composition of the biomass fuel and the combustion conditions. These chemical components can have properties like those found in clay, a common material used in fired brick production.

The development of fired clay bricks to be lightweight and have good insulating properties that utilize agricultural and industrial waste materials has been considered. However, other clay brick properties have also been claimed to be important. The properties of fired clay bricks depend on the composition of raw materials, firing temperature, and production method [11].

SBE and BA can be used as supplementary materials in fired brick manufacturing, potentially providing a source of silica and alumina. The chemical components of SBE and BA can vary depending on their source and composition. However, typical chemical components of SBE and BA that may be relevant to fired brick production include silica (SiO_2). SBE and BA can contain varying levels of silica, a key component in fired bricks, as it contributes to their strength and durability. Alumina (Al_2O_3): SBE and BA can also contain alumina, known for its refractory properties and can enhance the heat resistance of fired bricks. Other minerals and oxides: SBE and BA may also include other minerals and oxides, such as calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O), and sodium oxide (Na_2O), which can affect the properties of the fired bricks [4][5][6][7]. Hence, this study assessed the potential of SBE and BA for bricks production and determined their properties in water absorption, flexural strength, and compressive strength.

2. MATERIALS AND METHODS

2.1 Research Design

This research study utilized the quantitative design of research to attain the objectives. The researchers undertook the production and evaluation of bricks, and the quantitative data was gathered by evaluating bricks' mechanical properties. In terms of data presentation, descriptive statistical analysis was used in analyzing the quantitative data.

2.2 Sample Preparation

SBE and boiler ash are collected and gathered from Filipinas Palm Oil Incorporation and Caraga Oil Refining Inc. at Rosario Agusan Del Sur, Philippines. The boiler ash contains shredded empty fruit bunch, wood, and coconut shells, which are burnt in the boiler's furnace. The spent bleaching earth is a byproduct of Caraga Oil Refining Inc after bleaching oil, a step in the crude oil refining process. The collected materials have undergone manual cleaning, such as removing impurities, which can affect the process and the product's properties. After removing impurities, the materials were stored in a container at room temperature.

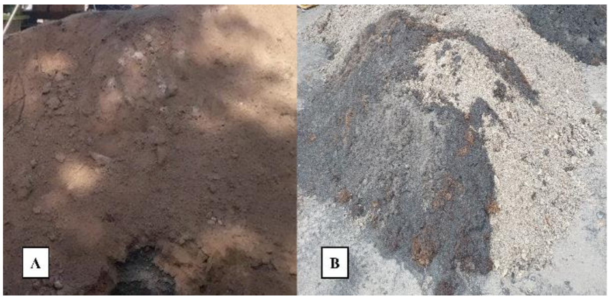

Fig. 1. (A) Spent Bleaching Earth (SBE) and (B) Boiler Ash

2.3 Experimental Design

Response surface methodology (RSM) is a statistical technique used to determine the relationship between multiple independent variables and a response of interest. RSM involves using mathematical models to predict and optimize the response of interest by varying the levels of the independent variables [12].

Central composite design (CCD) is a commonly used experimental design technique in RSM [13]. It involves a set of experimental runs that systematically vary the levels of the independent variables to generate a quadratic response surface model. CCD is often used to determine the optimal levels of the independent variables that will result in the desired response.

This study used a suitable Central Composite Design for two factors. Six (6) central points and eight (8) non-central points were used as the number of runs for the experiment. The thirteen (13) treatment runs are presented in Table 1, showing the different mixtures for each run.

Table 1. Summary of Brick Mixture

Trial Number	Mixture Proportion of Bricks		
	SBE (kg)	BA (kg)	10% Water (mL)
T1	1.65	0.538	218.8
T2	1.8	0.6	240
T3	1.5	0.6	210
T4	1.65	0.75	240
T5	1.65	0.75	240
T6	1.8	0.9	270
T7	1.862	0.75	261.2
T8	1.65	0.75	240
T9	1.438	0.75	218.8
T10	1.65	0.962	261.2
T11	1.65	0.75	240
T12	1.5	0.9	240
T13	1.65	0.75	240

2.4 Bricks Production Process

Following the thirteen (13) treatments set for Response Surface Methodology, thirteen (13) mix designs with different quantities of spent bleaching earth and boiler ash, then adding of water about 10% of the total weight per treatment (for semi-dry pressing) were prepared. After mixing, each treatment mixture was placed in a plastic bag for aging and set for 12 hours before proceeding to the next process, which is the molding of bricks. The researcher used a hydraulic press machine in the molding process; the researcher manually pumped the machine until the desired hardness of the molded bricks was achieved. Each treatment was molded into five (5) rectangular-shaped bricks with a size of 100 mm by 20 mm by 100 mm for better workability for the evaluation. After molding, the molded bricks were placed in a room for Air drying for 48 hours at room temperature, sun drying for 12 hours, and oven drying for 6 hours at 100 °C. The bricks must be dried and have become sufficiently hard before firing. The researchers ensured the bricks were dried enough and ready for firing. The last process of producing a brick is putting it in a kiln for the firing process; after the researcher ensures that the drying process of the molded bricks is enough and the bricks are ready enough to proceed into the firing process, the bricks are placed inside the kiln one by one. They preheated at 100°C for 30 minutes, then raised their temperature to 570°C for 30 minutes, then raised it to 900°C for 1 hour. The total consumed time for firing the bricks was 7 hours. The cooling process of the fired bricks takes time, and the kiln was opened the following day. Then, bricks were taken out of the kiln one by one.

2.5 Bricks Evaluation

A series of tests were conducted in this research to evaluate its mechanical property and durability properties. Under its mechanical property, first was the Flexural Strength Test; this test indicates the brick's ability to resist deformation under load. Second was the Compressive Strength Test, which establishes the crush resistance of a brick. The durability property was the Water Absorption Test, which indicates that the brick's water absorption can affect the quality and the bond strength between the bricks and mortar in masonry structures, reducing its strength properties.

2.5.1 Flexural Test

For the flexural strength test, the researchers used a manually operated Modulus of Rupture Testing Machine to conduct the flexural strength test of the bricks. The bricks were measured for their size (length, width, depth/breadth). The results gathered from the tester were the distance traveled by the reader, known as x, or the number of divisions or rotation of the dial. This data is then used for the calculation of Force using the MOR Calibration as follows:

MOR Calibration:

$$F = y(9.8) \tag{1}$$

Where:

x – dial reading, number of divisions
y – breaking force,
kgf ------ y=0.2669 + 0.1809x

Three-Point Flexural Strength:

$$\sigma = \frac{3FL}{2bd^2} \tag{2}$$

Where:

F is the load (force) at the fracture point (N)
L is the length of the support span
b is width
d is thickness

2.5.2 Compressive Test

Using a compression machine, the compressive test determines the compressive strength of bricks. It is also known as the crushing strength test of bricks. The result is expressed in kN/mm² and converted to MPa.

Compressive Strength:

$$\sigma = \frac{F}{A} \tag{3}$$

Where:

F is the applied force at the time of failure (ultimate load)
A is the area of the bricks in contact

2.5.3 Water Absorption Test

The absorption test will be used to indicate the durability properties of the bricks, such as quality, degree of burning, and the behavior of the brick in weathering. And the result is expressed in percentage (%). The test specimens were immersed in water at room temperature for 24 hours. The samples were weighed, and the water absorption was calculated using the following equation [14].

Water absorption:

$$W = \frac{M_2 - M_1}{M_1}(100) \tag{4}$$

Where:

M1 is the initial weight of the bricks (dry condition)
M2 is the weight of the bricks (wet condition)

2.6 Statistical Analysis

The experiment data was analyzed statistically using the Response Surface Methodology (RSM) method. The software used in the analysis was Design Expert v.13.

The following parameters were computed for the study.

1. Flexural Strength
2. Compressive Strength
3. Water Absorption

In setting optimization Parameters, the researchers used the maximizing and minimizing optimization goals for a particular response or dependent variable. These terms indicate whether the specific response requires an increase or decrease in value during optimization. Maximizing a response variable aims to achieve the highest possible value for that variable. Conversely, when you choose to minimize a response variable, you want to achieve the lowest possible value for that variable.

3. RESULTS AND DISCUSSION

3.1 Bricks Description

The bricks are rectangular blocks made of SBE and BA. The size of the bricks is 100 mm by 20 mm by 100 mm, with a reddish color on their physical appearance. Figure 2 below shows the actual product of the bricks made of SBE and BA.

Fig. 2. Bricks made from SBE and BA

3.2 Bricks Properties Evaluation

After production, the bricks were evaluated in terms of their Mechanical Properties. Under it are Flexural

Strength and Compressive Strength. Its durability property is Water Absorption. The randomization and determination of different treatment combinations of varying amounts of SBE and Boiler Ash were identified using the response surface method with a central composite design. The summary of the result is shown in Table 2.

Table 2. Summary of the Bricks Properties Evaluation

SBE, kg	BA, kg	Flexural Strength, MPa	Compressive Strength, MPa	Water Absorption, %
1.65	0.54	0.298	0.680	22.47
1.8	0.6	0.989	1.995	24.72
1.5	0.6	0.583	0.450	25.31
1.65	0.75	0.428	1.495	20.97
1.65	0.75	0.765	1.285	25.59
1.8	0.9	0.782	2.040	21.99
1.862	0.75	0.419	1.515	24.54
1.65	0.75	0.765	0.690	26.62
1.438	0.75	0.376	1.085	25.62
1.65	0.96	0.307	1.335	25.55
1.65	0.75	0.471	0.925	28.86
1.5	0.9	0.246	0.465	27.39
1.65	0.75	0.428	0.960	28.01

3.2.1 Flexural Strength

The flexural strength of a clay brick refers to its ability to resist bending or breaking under an applied load or force. This strength is important for determining the suitability of the brick for use in construction applications, where it may be subjected to various types of stress and strain.

As shown in Table 2, the average flexural strength of the brick's samples ranged from 0.246 MPa to 0.989 MPa. The highest flexural strength was achieved with a mixture of 1.8 kg of SBE and 0.6 kg of BA. A surface regression model analysis and Analysis of Variance (ANOVA) were conducted to determine the effect of the two factors in measuring response.

The results show that the linear model was found to be adequate for predicting flexural strength. Which was given by the following equation:

$$FS = -0.519767 + 0.836400A - 0.443981B \qquad (5)$$

Where:

FS – Flexural Strength, MPa
A – Spent Bleaching Earth, kg
B – Boiler Ash, kg

Table 3. ANOVA of Linear Model for Flexural Strength

Source	Sum of Squares	df	Mean Square	F-value
Model	0.16	2	0.08	1.71^{ns}
A-Spent Bleaching Earth	0.13	1	0.13	2.67^{ns}
B-Boiler Ash	0.04	1	0.04	0.75^{ns}
Residual	0.47	10	0.05	
Lack of Fit	0.34	6	0.06	1.82^{ns}
Pure Error	0.13	4	0.03	
Cor Total	0.63	12		

ns – not significant R^2 – 0.26

The Analysis of Variance (ANOVA), as presented in Table 3 for the Linear model, showed the model was not significant. Nonetheless, the Lack of fit was not significant, concluding that the model was good at predicting the response.

As observed in Table 3, R^2 is equal to 0.26, which indicates that the model may not be a good fit for the data or that other variables or factors may influence the dependent variable. Additionally, further analysis showed no significant effect of the varying levels of SBE and BA on the flexural strength of the bricks.

However, it can be observed in Figure 3 that the increasing value of SBE brings a linear effect, increasing the flexural strength of the bricks. This result is primarily due to the amount of silica and alumina present in SBE that can increase the flexural strength of the bricks. Moreover, SBE and BA may have different particle size distributions. When SBE content increases, it can potentially contribute to finer particles in the brick composition. Finer particles tend to fill the voids between coarser particles and improve the compactness of the material. This filling effect increases the interparticle contact and enhances the flexural strength.

On the other hand, BA with coarser particles may not fill the voids as effectively, resulting in reduced flexural strength [15]. This outcome is similar to the study by Nataraja et al. [16], who used SBE and quarry dust to replace clay in brick production partially. The results showed that the flexural strength of the bricks increased with an increase in the percentage of SBE.

However, according to ASTM C62-19 Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale), the minimum average flexural strength requirement for fired clay bricks is 1.4 MPa (200 psi) [17]. This standard indicates that the developed bricks are not suitable for load-bearing projects; hence, other factors must be included in future studies to enhance the flexural strength of the bricks made from SBE and BA.

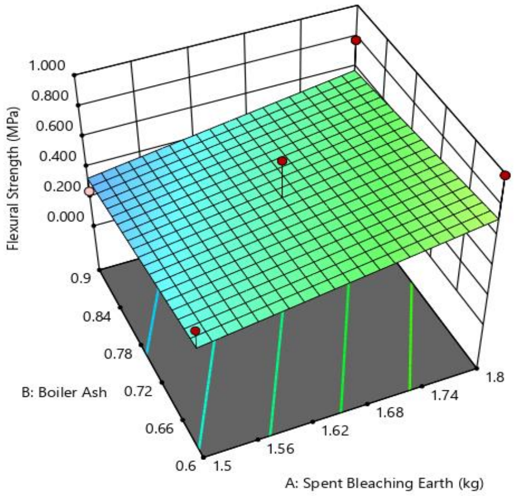

Fig. 3. Surface plot for flexural strength

3.2.2 Compressive Strength

The compressive strength of a clay brick refers to its ability to withstand crushing or deformation under an applied load or force. It is an important mechanical property for evaluating clay bricks' structural integrity and durability in various construction applications. As shown in Table 2, the average result of the compressive strength of the brick samples ranged from 0.45 MPa to 2.04 MPa. The mixture with the highest compressive strength is 1.8 kg of SBE and 0.9 kg of BA.

A surface regression analysis shows that a linear model was the most suited model for predicting the compressive strength of the bricks in relation to the amount of SBE and Boiler ash. Which was given by the following equation:

$$CS = -4.59753 + 3.10830A + 0.822039B \quad (6)$$

Where:

CS – Compressive Strength, MPa
A – Spent Bleaching Earth, kg
B – Boiler Ash, kg

Table 4. ANOVA of Linear Model for Compressive Strength

Source	Sum of Squares	df	Mean Square	F-value
Model	1.86	2	0.93	6.49*
A-Spent Bleaching Earth	1.74	1	1.74	12.12*
B-Boiler Ash	0.12	1	0.12	0.85^{ns}
Residual	1.43	10	0.14	
Lack of Fit	1.03	6	0.17	1.70^{ns}
Pure Error	0.40	4	0.10	
Cor Total	3.29	12		

* - significant R^2 – 0.56
ns – not significant

Based on the result of the ANOVA for the Linear model presented in Table 4 shows a significant effect of varying amounts of SBE on the compressive strength of the bricks. These results can be supported by looking at the surface plot Figure 4 for compressive strength, wherein the increasing amount of SBE resulted in an increased compressive strength value. This result is primarily due to the silica and alumina content present in SBE, which can increase the compressive strength of the bricks. This is also observed in the study of O Rokiah et al. [18]; the study is about the effect of SBE content on the compressive strength of foamed concrete. The result showed that compressive strength increases with the increase in the percentage of SBE as cement replacement. BA and SBE may enhance the binding characteristics of the brick matrix. They can provide additional fines, surface area, or reactive components that improve particle adhesion and contribute to better inter-particle bonding. This enhanced binding mechanism strengthens the brick structure and increases compressive strength.

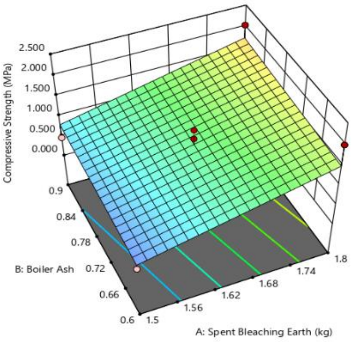

Fig. 4. Surface plot for compressive strength

However, according to ASTM C62-19 Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale), the minimum average compressive strength requirement for fired clay bricks is 7.0 MPa (1000 psi) [17]. Despite not meeting the ASTM standard for compressive strength, the bricks may have possessed other advantageous properties or characteristics that rendered them suitable for alternative applications. Non-structural uses, for instance, included employing low-strength bricks for decorative purposes, cladding, landscaping, or as partitions that did not bear loads.

3.2.3 Water Absorption

Water Absorption refers to the movement of liquids within solid pores caused by surface tension in capillaries. The higher the water absorption, the less durable the brick unit is [19]. This range ensures that the bricks are sufficiently porous to allow for moisture transfer but not so porous that they are susceptible to damage from freeze-thaw cycles and other weather-related factors [20]. As shown in Table 2, the average result of the water absorption of the bricks samples ranged from 20.97 % to 28.01 %. The desired water absorption of the bricks must be as low as 10% to 20%. In this case, the mixture with the most acceptable percentage of water absorption is at 1.8 kg SBE and 0.6 kg BA, with a value of 20.97%. On the other hand, the mixture combination with the highest percentage of water absorption is at 1.5 kg SBE and 0.9 kg BA with a value of 28.01%.

The surface regression analysis shows that the linear model was the most suited model for predicting the percentage of water absorption by the bricks in relation to the amount of SBE and BA. Which was given by the following equation:

$$\mathrm{WA} = 33.22870 - 6.26757\mathrm{A} + 3.08731\mathrm{B} \quad (7)$$

Where:

WA – Water Absorption, %
A – Spent Bleaching Earth, kg
B – Boiler Ash, kg

Table 5. ANOVA of Linear Model for Water Absorption

Source	Sum of Squares	df	Mean Square	F-value
Model	8.78	2	4.39	0.78^{ns}
A-Spent Bleaching Earth	7.07	1	7.07	1.26^{ns}
B-Boiler Ash	1.72	1	1.72	0.31^{ns}
Residual	56.10	10	5.61	
Lack of Fit	18.03	6	3.00	0.32^{ns}
Pure Error	38.07	4	9.52	
Cor Total	64.88	12		

ns – not significant R^2 – 0.14

As presented in Table 5, the R^2 is equal to 0.14, indicating that the model may not be a good fit for the data or that other variables or factors may influence the dependent variable. It further shows that varying amounts of SBE and BA cause no significant effect. Moreover, as observed in the surface plot of water absorption (Fig. 5), the varying amounts of SBE and BA produced a relatively equal amount of water absorption percentage. However, observing the amount of SBE alone, increasing the amount of SBE in the brick increases water absorption. SBE, known as calcium-bentonite, primarily comprises montmorillonite minerals with high water absorption capability. Calcium-bentonite demonstrates adsorbent properties due to its small colloidal particle size and significant surface capacity for adsorption. The value of water absorption by brick is strongly influenced by the pores or cavities in it [16].

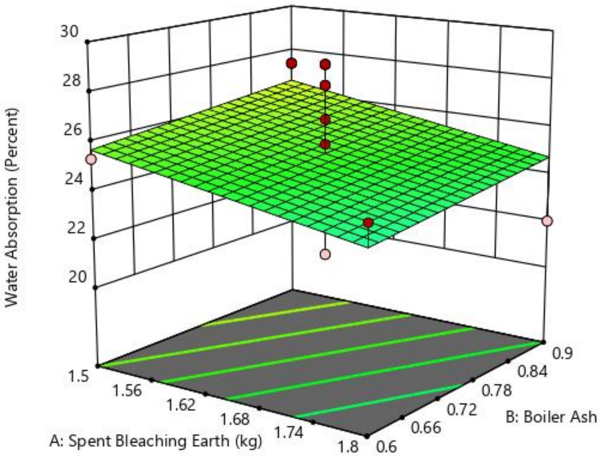

Fig. 5. Surface plot for compressive strength

3.3 MIXTURE OPTIMIZATION

A graphical optimization method was used to determine the optimum mixture of SBE and BA, which used the contour plot for each response during the evaluation. The optimization criteria are shown in Table 6. As shown in Table 6, the optimization goal of flexural strength and compressive strength was set to "maximize" because the goal is to attain the highest value of the bricks' compressive strength and flexural strength. The water absorption was set to "minimize" to get the lowest value, as the researcher wanted to attain the standard water absorption value in percentage. The overlay plot for flexural strength, compressive strength, and water absorption is shown in Figure 6. The yellow region in the figure is the acceptance mixture of SBE and BA for brick development.

Table 6. Optimization Criteria

NAME	GOAL	LOWER LIMIT	UPPER LIMIT
Flexural Strength	Maximize	0.2461	0.9894
Compressive Strength	Maximize	0.45	2.04
Water Absorption Strength	Minimize	20	28.86

To support the optimum condition determined in graphical optimization, numerical optimization was conducted to assess the desirability of every mixture. A desirability of close to one (1) indicates a better mixture. The results presented in Figure 7 show that the optimum condition that can give the desired properties of bricks is having a mixture of SBE equal to 1.8 kg and a BA of 0.6 kg, which provides a desirability with a factor of 0.644.

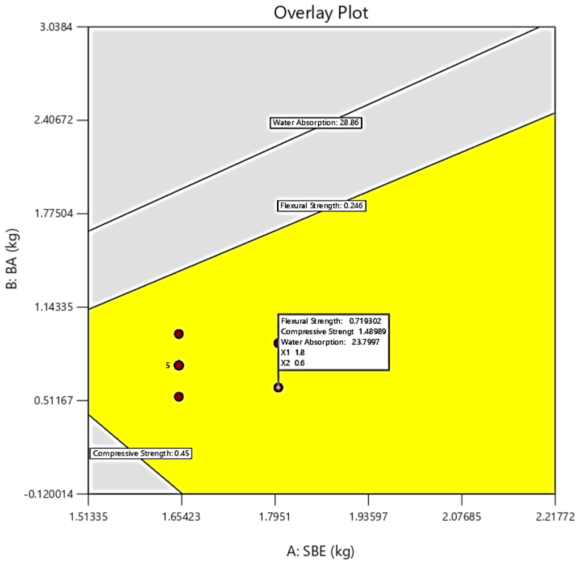

Fig. 6. Optimum condition obtained by the contour plot.

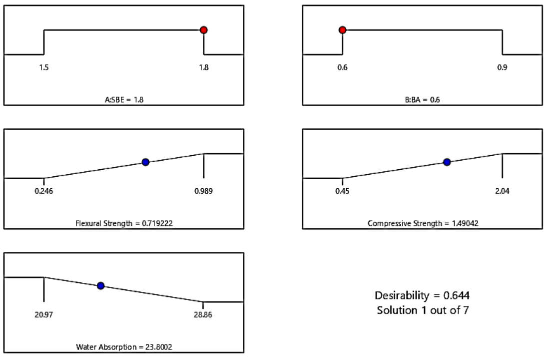

Fig. 7. Solution result for numerical optimization

4. CONCLUSION

Spent bleaching earth (SBE) and boiler ash (BA) can be used as raw materials in brick production, reducing waste and promoting sustainable development. Regarding compressive and flexural strength, a higher amount of SBE than BA improved the bricks' compressive and flexural strength. On the other hand, the water absorption percentage remained relatively equal when different quantities of SBE and BA were used.

Furthermore, the model developed is a great help in predicting the response. However, there is a need to include other variables that could affect the bricks' mechanical properties to enhance the model developed in this study. Based on the optimization result, 1.8 kg of Spent Bleaching Earth (SBE) and 0.6 kg of Boiler Ash (BA) will be the optimum raw material mixture to give the desired responses.

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