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Utilization of Fly Ash as Incorporate Material to Produce Construction Bricks Through Firing Method – A Review

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Abstract: Brick one of the most important structural components in construction work that used to build walls, pavements and other elements in masonry construction. Today, practically every country uses bricks to construct buildings, and around 30% of the world's population still lives in earthen structures that were once used as shelters. The management of waste products is one of the world's most serious environmental challenges. Thermal power facilities generate a lot of waste, primarily in the form of ash, which can be harmful if not properly managed. The purpose of this study is to review the production bricks by utilizing the waste material, which is fly ash (FA) by through a conventional firing method. Pervious researchers referred to various standard such as British Standard (BS), American Society for Testing and Materials (ASTM) and Indian Standard (IS) to conduct their evaluation tests on the brick samples. Based on the previous research, this review study found that most of bricks' compressive strength would reduce when the water absorption increases. This phenomenon influence by many factors such as rise in proportion of FA content and variety of firing temperature rate. Despite many studies, commercial manufacture of bricks from waste materials remains extremely limited. The slow acceptance of waste-based bricks by industry and the public could be one of the reasons. Therefore, insistence on the both domestic and foreign construction industry to plays a decisive role to promote and utilise waste material such as FA in FA-clay incorporated brick production.

Keywords: Clay Bricks, Fly Ash, FA-clay Incorporated Bricks, Firing.

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1. Introduction

Brick is one of the most significant structural elements in construction activity that complement the building structure. Nowadays, it can be said that almost one world is utilizing the bricks to construct buildings and approximately 30% of the population of the world still live in earthen structure as it has been used for shelters purposes [1]. China and India are the world-leading in producing brick with annual brick production, 180 billion tons of common fired clay bricks, equating to 340 billion tons of clay [2]. Along with the passage of time and technological advances, the manufacture of bricks also evolved. materials in the manufacture of brick are not limited to clay only, but various other materials are also mixed to improve the performance of the brick products.

One of the world's biggest environmental issues is the handling of waste materials. According to Figure 1.1, timber, brick, packing, concrete, and steel were the most common materials generated. Brick waste accounted for nearly 26% of the total construction waste, making it the second-largest component [3]. The use of brick made from waste material such as fly ash (FA) also now has a place in the construction industry in Malaysia. The main industrial waste material is FA which commonly produced by thermal power plants [4]. The reuse rate for FA approximately 47% from its production. The production of waste material at the thermal power plant will continue to increase over time. The utilization of waste material such as FA not only increased the brick performance, but it would also reduce the environmental problem such as pollution, generate a lot of unused waste and emission of a high level of energy. The manufacture of fired clay brick utilizing waste material will help reduce the environmental damage generated by waste deposition on exposed landfills and improve the efficiency of brick at low production costs, resulting in more sustainable construction. Moreover, it is one of the sustainable solutions for saving the environment by reusing unused waste material.

The purpose of this study is to review the production bricks by utilising the waste material which is FA through a conventional firing method. There are various standards that has been used by researcher to conduct their compressive test and water absorption test. However, the procedure in every standard is quite similar to one another, they just formulated differently because to be adapted with the circumstances of a particular area. One of the standards used in the study reviewed in this paper is ASTM by Abbas et al. [2]. In their study, the mechanical properties of brick sample were obtained according to ASTM C27, while for the durability properties of brick samples were determined as per ASTM C67.This study concentrates by reviewing the compressive strength and water absorption of bricks made of FA via firing process and reviewing the excellent implementation of the firing process with excellent properties of the bricks which would be produce. There are some research questions designs in assisting to conduct this review study. The research questions are listed as below:

- **RQ1:** What is the best percentage of the proportion of FA that would give the best performance of the incorporated bricks?
- **RQ2:** What is the optimum temperature for the firing process for incorporated FA-clay brick?
- **RQ3:** How would the addition of FA affect the water absorption rate of the bricks?
- **RQ4:** Is the addition of FA to the brick’s mixture can leads to improvement of bricks strength?
- **RQ5:** How the water absorption would affect the strength of the incorporated FA-clay brick?
- **RQ6:** What are the differences in performance between incorporated FA-clay bricks compared to conventional clay bricks?

2. Literature Reviews

2.1 Fly Ash

A large number of by-products commonly known as fly ash (FA) are created by the use of fuel such as coal, bio briquettes, and wood in various industrial unit [5]. As stated in the Eighth Malaysian Plans 2008, more than 11 million tonnes of coal are utilized annually in Malaysia and over 2 million tonnes of coal ash are produced annually. FA consists of silt-sized particles where is normally spherical, usually between 10 and 100 μm in size [6]. FA is finer than lime and Portland cement. The fluidity and workability of fresh building material such as brick and concrete are enhanced by these small glass spheres. The main chemical compounds of FA are SiO_2, Al_2O_3 and Fe_2O_3 with some minor elements such as CaO, MgO and other oxides [7]. The proportion of chemical compounds in FA might vary according to its class and it has similar properties as in Portland cement as shown in [8]. According to ASTM C-618, FA is divided into two types, which are Class F and Class C. The chemical composition of the ash itself is the major distinction between Class C and Class F FA where the amount of calcium, silica, alumina, and iron is different for both classes.

2.2 Firing Method

Brick is fired to modify their physical structure and provide good mechanical characteristics as well as resistance to water slaking [9]. The firing process, if done correctly, should reduce the possibility of problems such as:

i. The cracking of brick as a result of insufficient moisture removal before burning.
ii. Insufficiently hard-fired brick with low strength.
iii. Fired bricks came in a variety of sizes, although the bricks were all the same size.

Usually, at manufacturing factories, bricks are fired in the kiln because they were produced in large scale of bricks production [2]. Other than that, bricks could also be fired by furnace or oven at laboratory if the production of the brick is small scale or just for the experiment purpose [10]. Depending on the kiln or other firing equipment and conditions, brick is fired between 10 to 40 hours, but the duration also can be varying. It is recommended that a low heat be provided to the bricks first to drive off any residual moisture, regardless of the firing technique utilized.

2.3 Review of research on utilisation of fly ash to produce incorporated brick

Many studies have been made to incorporate industrial waste in the production of bricks as shown in Table 1 for environmental concerns and sustainable development but still adopt the typical firing process [11]. A wide range of waste products, especially FA, have been studied.

Sutcu et al. [6] experimented on the properties of bricks containing clay, FA and bottom ash BA. The result shows that the fired bricks containing FA and BA as a clay replacement for 5% to 30% increase the water absorption and lower the compressive strength. The bricks dimension was 12 × 40 × 80 mm and dried for 40˚C and 100˚C for 24h. The bricks sample which fired at a rate of 2.5˚C/min until 600˚C, 5 ˚C/min until the temperatures of 950˚C and 1050˚C produce less than 22% of water absorption value. Owing to the porosity of the brick samples, the samples fired at 950˚C offered slightly higher water absorption than those fired at 1050˚C. Moreover, the brick samples containing FA and BA had a lower value of compressive strength with an increase of the weight (in %) in each sample.

Elavarasan et al. [12] studied the utilization of FA waste and Manufactured-sand (M-sand) in various construction materials such as bricks. Brick samples were prepared by mixing different proportion of FA and M-sand from 20% to 40% with clay and dried the bricks at ambient condition for 7 until 10 days and firing the dried bricks in an electric furnace at a temperature of 204˚C until 1300˚C for 48h to 72h. To evaluate either volume of bricks affected the compressive strength or not, several brick samples dimensions had selected. The volume of brick samples did not have a significant influence on the compressive strength of the specimens which only gives a different value of ±0.2. The compressive strength of the brick samples with different composition of FA and M-sand was increase with increasing the proportion of the FA in the samples and they had a higher value of compressive strength if compared to the M-sand incorporated brick samples.

Taki et al. [13] investigated the possible utilization of FA for stabilizing sewage sludge (SS) sustainable replacement of conventional fired clay brick in India. The study result has shown that the water absorption was found to be decrease with the increasing of FA content in SS bricks specimens with 70 × 70 × 70 mm and 20 × 20 × 20 mm dimensional. The replacement of SS with clay is the major contribution to higher water absorption and high expansive behaviour. It is found that the compressive strength increases for 0% to 40% and 0% to 60% of incorporating FA bricks for 70 × 70 × 70 mm and 20 × 20 × 20 mm dimensional respectively but beyond the proportion, it decreases. These are because of the effect of crushing FA due to its hollow spherical nature under applied pressure during the sample's preparation.

Türkel & Aksin [14] evaluated the possibilities of a combination of FA and Phosphogypsum (PG) to replace clay as a conventional material in the production of construction bricks. This study used FA, weathered PG, and clay as the main raw materials with mixture proportion 0% to 30%, oven-dried the sample materials for 24h at 105˚C, fired at 1000˚C in the oven for 8h. Precaution step has been taken to avoid rapid evaporation occurred that could affect the final results. This study obtained that the compressive strength had decreased when the proportion of the FA increase because it has low in unit weight but high in water absorption. Water absorption value in this study was increased when the proportion of FA increase and found to be varied between 19% and 38%. Besides, FA had a higher rate of absorption if compared to the PG incorporated specimens. The incorporated cylinder samples also show that they resist high firing temperature where the control clay specimens only survive until 1000˚C, beyond that its damage.

Leiva et al. [7] studied the feasibility of utilizing co-combustion FA as a product of eco-friendly fired bricks by implementing the 27 × 40 mm, 27 × 80 mm, and 27 × 160 mm as the dimensional cylinder brick specimens. Three levels of temperatures which are 800˚C, 900˚C and 1000˚C used to evaluate the effect of the temperature on the properties of the final products. The samples consist of 0% to 100% of FA and clay show that the water absorption decreased with increases with the firing temperature at 800˚C and 900˚C and increases in proportions of FA but decrease at 1000˚C due to the absorption of water is inverse with the samples' density. The compressive strength of the brick specimens shows that when the temperature is increased, the compressive strength also increases for all composition. For 800˚C and 900˚C firing temperature, the compressive strength decreases accordingly when the proportion of FA in samples increases.

Sokolář & Nguyen [15] investigated the influence of FA on the properties of plastic clay and fired bricks. Class C FA was utilized as raw material to mix with clay to produce 100 × 50 × 20 mm size brick samples. Brick samples with two different proportions of FA which are 0% and 10% undergo a dry-mixing process of 24h, moisten phase process, opened-air dried with an average temperature of 21˚C, oven-dried with an average temperature of 110˚C, fired using electric kiln with the temperature at 850˚C and 1000˚C and immersed underwater at depth 10 mm. Then, it is allowed to dry at 110˚C for 24h after seven days. This investigation found that the addition of FA in clay-based material bricks increase the water content, plasticity of clay bricks achieved the required ratio and decreases the value of drying shrinkage. The addition of FA into the clay brick affects the formation of the pore in the samples where there is a reduction of bulk density and increase water absorption of the samples.

Moyo et al. [16] experimented with the utilization of coal FA in the production of ammonium nitrate corrosion-resistant brick. From the test conducted onto 100 × 50 × 35 mm dimensional brick samples, the amount of water absorption decreases with the increase of amount sodium silicate solution added. The brick samples with different proportion of sand, cement, water, and solution of sodium silicate were dried using heat from the sun while sprinkling water three times a day for 3-5 days, heated at 250˚C, and heated at a temperature of 105˚C and 115˚C until they reached a substantially constant weight. The average percentage of water absorption is range from 13.68% to 23.05%, indicated that the addition of sodium silicate would improve the quality and performance of the bricks. The compressive strength of brick samples increases when the amount of sodium silicate increased. The highest compressive strength is 32.29 MPa which contributed by the brick sample of the proportion of FA – 30%, sand – 40% and cement – 30% with 125 ml addition of sodium silicate.

Abbas et al. [2] were conducted the test to investigate the effect of FA on the properties of mechanical and durability of the fired clay bricks in Pakistan. The 225 × 112 × 75 mm bricks samples with 0% to 25% of FA was added with 18.70% to 20.8% of water to get the homogenous mixture. The water absorption of the samples found to be increased with increasing of FA content in the mixture samples with 24% as its highest percentage. Besides, the compressive strength of brick specimens fired at 800˚C found to be decreased when the percentage of the FA incorporated increase. The compressive strength will be decreased when the porosity of the brick specimens increases. Nonetheless, all the incorporating FA bricks specimens still satisfy the minimum requirement of the compressive strength as per Pakistan Building Code.

Naganathan et al. [4] were investigated the performance of the construction brick made up of FA and silica fume as BA. In preparing 200 × 90 × 60 mm dimensional brick samples, the raw material dried in an oven at a temperature of 110˚C for 3h and mix with cement and water (to get the homogenous mixture) to evaluate their compressive strength, water absorption, and others physical and mechanical properties. The result of this investigation shows that when the proportions of FA and cement were increased, the strength would be increased too, where the compressive strength in this investigation was between 7.13 MPa and 17.36 MPa. Water absorption for the brick samples was ranged between 12.6% and 29%. Most of the tested brick samples were founded over absorb since the typical water absorption of bricks for mild weather is 22% and severe weather is 12%. The brick was fired in an oven for 20 days at a temperature of 200°C experienced high water absorption since the FA is water absorbent.

Esmeray & Atıs (2019) [17] studied the usage of sewage sludge (SS), oven slag (OS) and FA to produce clay bricks. With an additional of 5%, 10% and 15% of SS, OS and FA, the brick samples were tested on their apparent porosity, water absorption, compressive strength, shrinkage, pressure strength, etc to evaluate their behaviour. Based on the results obtained from the experiment, the samples of brick with the addition of class F FA were affected with the different firing temperature. The 8 mm size samples fired with temperature 900˚C had a higher water absorption rate compared to sample fired with 1050˚C. As the temperature increasing, the water absorption value decreases. The compressive strength of all the specimen was fallen considerably if compared to the control sample. The samples with an additional 15% of FA and SS observed to be the weakest bricks samples which have the maximum rate of water absorption. Accordingly, increasing the waste diversity in the brick specimen not quite change the properties of the brick samples positively but with the right proportions of mixtures, the brick will be resulting in optimum water absorption and strength.

Table 1: The previous studies of incorporating FA bricks through firing method

No.	Brick size (mm)	Drying/firing condition	Tests conducted	Reference
1.	12 × 40 × 80	Dried in the oven for 40˚C and 100˚C for 24h and fired for 2 h with a rate of 2.5 ˚C/min until 600˚C, 5 ˚C/min until the temperatures of 950˚C and 1050˚C.	Porosity, water absorption, apparent specific gravity, bulk density, compressive strength, and thermal conductivity.	[6]

Table 1: The previous studies of incorporating FA bricks through firing method (continued)

No.	Brick size (mm)	Drying/firing condition	Tests conducted	Reference
2.	215 × 98 × 82, 218 × 95 × 85, 200 × 89 × 81, 198 × 91 × 81, 202 × 92 × 80, 201 × 92 × 85, 192 × 93 × 83, 195 × 91 × 85, 197 × 94 × 82, 198 × 95 × 80.	Dried the bricks at ambient condition for 7 until 10 days and fired the bricks in an electric furnace at a temperature of 204˚C until 1300˚C for 48h to 72h.	Water absorption, specific gravity, and compressive strength.	[12]
3.	70 × 70 × 70, 20 × 20 × 20	Air-dried, oven-dried at 100˚C for 24h and fired at 1000˚C in a muffle furnace for 10h.	Compressive strength, water absorption and efflorescence.	[13]
4	27 × 80, 27 × 40, 27 × 160 (Cylinder Shape)	Dried for 24h at laboratory condition and 105˚C and fired at 1000˚C.	Unit weight, compressive strength, flexural strength, water absorption And shrinkage.	[14]
5.	32.5 × 50 (Cylinder shape)	Dried at 60˚C and fired at 800˚C, 900˚C and 1000˚C.	Bulk density, water absorption, shrinkage and compressive strength and leaching behaviour.	[7]
6.	100 × 50 × 20	Opened-air dried with an average temperature of 21˚C, oven-dried with an average temperature of 110˚C, fired using electric kilnwith the temperature at 850˚C and 1000˚C.	Plasticity, compressive strength, water absorption and efflorescence.	[15]
7.	100 × 50 × 35	Dried using heat from the sun with consistent sprinkling water three times a day, heated at 250˚C to achieve high strength and full force out all the silicate water and heated at a temperature of 105˚C and 115˚C.	Compressive strength, water absorption and corrosion resistance.	[16]
8.	225 × 112 × 75	Sun-drying for 4 to 5 days in open-air, oven-dried at 100˚C for 24h and fired at a temperature of 800˚C for 3 days.	Compressive strength, flexural strength, water absorption and efflorescence.	[2]
9.	200 × 90 × 60	Dried in an oven at a temperature 110˚C for 3h and fired in an oven for 20 days at a temperature of 200°C.	Strength, modulus of rupture, ultrasonic pulse velocity (UPV), water absorption, sorption, IRS and fire behaviour.	[4]

No.	Brick size (mm)	Drying/firing condition	Tests conducted	Reference
10.	8 mm in rectangular size	Dried at room temperature for 3 days in a place not exposed to sunlight, then the specimen was dried at 105 ± 5C˚ for 24h. Fired at 2 different temperatures; 900 C˚ and 1050C.˚	Apparent porosity, water absorption, compressive strength, shrinkage and pressure strength.	[17]

3. Discussion

This chapter was presented and discussed deeper the data and result that obtained from the previous studies by answering all the research questions that had been designed regarding the objective of the study.

3.1 Proportion of Fly Ash (FA)

Most of the researcher uses more than 10% of FA as an addition substance in producing incorporated bricks. Based on **Error! Reference source not found.** below, most of the studies utilised below 40% of FA in every sample of bricks and some of the study experimented by using 100% of FA in their study. This shows how important to design and determine what is the best percentage of FA proportion should be used so that product of bricks could provide the best and most optimal performance. On average, the best proportion of FA to be substitute with the clay soil to produce incorporated FA-clay brick is 20% to 40% of FA contents. A good bricks should have a compressive strength of 3.5 N/ mm^2 and a percentage of water absorbed of no more than 20% of its weight [12].

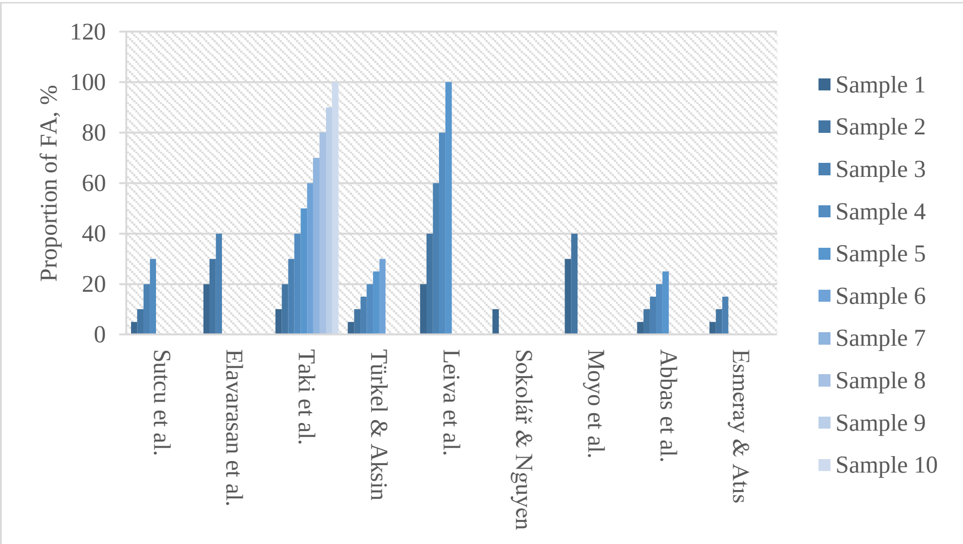

Figure 1: Various proportion used by the researcher of FA added in the mixture of incorporating FA bricks.

3.2 Firing Temperature

Figure 2 shows the firing temperature in ˚C utilised by some previous studies. It shows that most of the researchers utilised 800˚C and above firing temperature in their study. The range temperature used by some other researcher was 1000˚C and the highest temperature was 1300˚C. This proved that temperature also plays a big role in producing a good quality of bricks. The performance of brick is influenced by its firing temperature. The contribution of high degree sintering when the firing process approaching 1000°C is one of the factors the brick can be hard. The bricks fired with insufficiency temperature (heat) would be weak in durability and its stability. However, firing with higher temperatures would release a high rate of energy which is the cause of environmental issues. Therefore, it can be said that the optimum temperature for this FA-clay incorporated brick firing temperature is 800˚C to 1050˚C but still need to consider other aspects too.

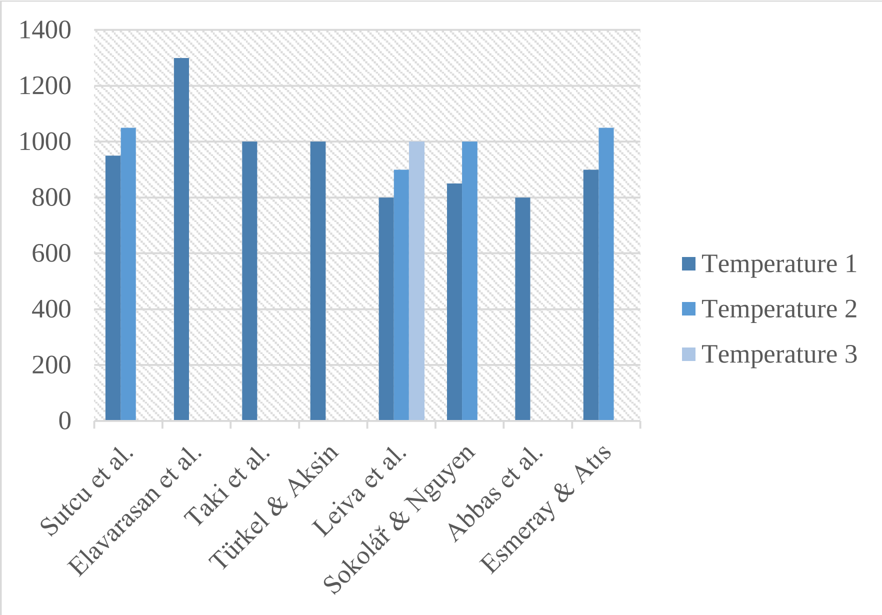

Figure 2: Firing temperature of the brick used for 8 previous study papers

3.3 Water Absorption

Based on the previous studies, most of the researchers immersed the brick samples in water for 24h (including the boiled and cooling process). According to BS 3921, the minimum periods for the brick samples immerse in the water is 16h and not more than 19h (addition with 5h boiling process). This shows that the optimum periods to allow the brick to immerse in water within 16h to 24h. The additional FA in the mixture of clay brick would make the water absorption of the brick samples increase. This is because the addition of FA would increase the porosity of the samples since the microporous structure contributes by the hollow spherical shapes of the FA which has pores size between 50 µm to 10 µm [6]. The apparent porosity in FA more way higher than clay. Thus, increasing the content of FA in the mixture contributes to the high pores in the mixture even though the clay fewer pores.

3.4 Compressive Strength

From the previous studies, there are various reading of the compressive strength obtained from the test conducted. Some of the findings show that compressive strength would reduce in increasing the FA content in the mixture and some of the others found to be increasing. The reduction of the compressive strength might be contributed by the high porosity of the FA since the FA particles are built up from micro-size of hollow spherical shapes [15]. Reasons for those who found the compressive strength rise when the FA content increased was the brick need to be fired at high temperature to obtain more strength. This is due to the higher degree of sintering when the brick fired at high temperature where the crystalline phases melt, flow and fill the internal pores due to surface tension force later make the brick stronger [7]. According to BS 3921, the minimum compressive strength for the brick is 5

N/mm^2 which is under damp-proof course 1 class. But still, all the tested bricks must possess this minimal standard requirement so that they use as construction material.

3.5 Correlations Water Absorption with Strength of Brick

The correlation between water absorption with compressive strength of the FA incorporated bricks could be varying. This is because the water absorption of the bricks can be influenced by factors such as apparent porosity, firing temperature and density etc. then, which would determine the compressive strength of bricks. From the previous studies, most of the researchers found that if the water absorption rises, the compressive strength would be decreasing. FA incorporated bricks may absorb more water because some water molecules could become trapped in the hollow structure since FA high in porosity which a contributor for water particles to fulfil all pores spaces. When there is too much water in a mixture, the bonding between the particles weakens, allowing the particles to slide against one another, resulting in low compressive strength in bricks. Furthermore, due to insufficient heat from the firing temperature, water absorption may not be reduced. A sufficient fire temperature must be reached to attain vitrification temperature, at which point the bricks would be at their hardest (high density) and most resistant, and their compressive strength could improve.

3.6 Performance of The FA incorporated Bricks

Every type of different bricks would give a different performance. Generally, bricks made completely of clay have better performance than incorporated bricks, but conventional clay bricks have given some negative side effects to their production. One of them is being a contributor to environmental problems. Most of the previous studies stated that incorporating FA bricks were given slightly lower performance compared to clay bricks. Factor such as porosity, rates of temperature influence the brick’s water absorption and compressive strength which determine the quality of brick performance. Table 2 shows the different result obtained from two previous researchers to study the performance of the incorporating FA bricks. As shown in the table, both clay brick and incorporating FA bricks were given different water absorption and compressive strength value. The clay bricks as a control brick were given higher compressive strength with low water absorption. This indicates that clay brick has a better performance compared to brick containing FA. However, it is not necessarily that FA-clay incorporated bricks are not good and cannot be used. In fact, they can still be considered as building materials if they pass all the standard requirements.

Table 2: The result obtained from the study by Sutcu et al., (2019) and Abbas et al., (2017)

Study by	Sutcu et al. [6]		Abbas et al. [2]	
Brick type	Clay Bricks	FA Incorporated bricks	Clay Bricks	FA Incorporated bricks
Proportion of FA, %	0	10	0	25
Firing temperature, ˚C	1050		800	
Porosity, %	21.3	27.5	-	-
Water Absorption, %	10.4	14.3	11.7	24.0
Compressive Strength, N/mm^2	35.5	23.0	23.0	8.0

4. Conclusion

Based on the objectives of the study, this review paper can be concluded by stating that:

i. The compressive strength and water absorption of an incorporated brick depend on various factors such as the proportion of FA used, the presence of pores in a brick mixture, firing temperature etc. In general, bricks with a high water absorption rate would produce low compressive strength.
ii. The addition of FA into the clay compound would increase the water absorption rate and reduce the compressive strength of a brick. The number of pores found in FA is higher compared to the number

of pores found in clay. Therefore, a high number of pores, allows water to be absorbed more so that the pore spaces are filled fully.

iii. The firing method of incorporating FA bricks still can be used as same as the conventional firing method. Firing temperature also plays an important role in determining the durability and strength of bricks. Higher temperatures will produce stronger bricks. Therefore, Incorporated FA brick needs to be fired with optimal temperature so that the water content can be reduced and allow the bricks to become harder.

5. Recommendation

After conducting this review study, the following recommendations were drawn:

i. More in-depth studies should be carried out to further study the production of bricks incorporating FA so that the performance of the bricks produced is comparable or better than conventional bricks.
ii. Studies on water absorption and compressive strength of bricks incorporating FA need to be continuously implemented to determine an optimal value for these two aspects.
iii. Commercial manufacture of bricks from waste materials remains extremely limited. The slow acceptance of waste-based bricks by industry and the public could be one of the reasons. Therefore, encouraging both domestic and foreign construction industry to plays a decisive role to promote and utilise waste material such as FA in FA-clay incorporated brick production.

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