Innovation of Interlocking Block Mixing with Biomass for Sound Absorption and Thermal Conductivity in Thailand

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Abstract
This study involved the application of natural materials to produce interlocking blocks for thermal conductivity and sound absorption by mixing rice straw and rice husk ash. The ratios of soil, cement and sand used in the mix was 5:1:1. The mixing ratios of rice straw were zero, 1, 2 and 3% and those of rice husk ash were 10, 20 and 30% of the weight of cement. The test included the measure of compressive strength, unit weight, water absorption, porosity, thermal conductivity and sound absorption using blocks at the age of 28 days. The results showed that the addition of rice straw caused the compressive strength to reduce, while porosity and water absorption were increased. The addition of rice husk ash helps to improve the compressive strength and unit weight. All of these qualities passed the Thai Industrial Standard TIS 58-2533 (TIS 1990). The increasing of rice straw and rice husk ash resulted in low thermal conductivity and better sound absorption. Therefore, rice straw and rice husk ash are interesting materials in the production of energy-saving building materials.

1. Introduction
Energy is very important in both industrial applications and other businesses. Currently, energy use is increasing continuously, resulting in a shortage of energy and resources as well as the destruction of the environment in order to obtain more energy sources. Thailand is a country that has energy problems. Therefore, it is necessary to find ways to reduce energy consumption. One choice that has an important role involves energy saving in buildings since most of the energy needed is used in buildings for heating and cooling (Balaras et al. 2000). Therefore, one of the most important factors is to improve the properties of the wall by reducing the heat conduction into the building and making the walls of buildings have high heat resistance, which will make the temperature inside the buildings suitable for living while reducing electrical energy usage from air conditioners. For a long time, materials such as concrete blocks, brick blocks and interlocking blocks have been used in a wide variety of construction applications for wall systems. The characteristics of these walls include hollow holes, which can reduce the heat conduction into buildings. However, these materials have higher thermal conductivity than the thermal conductivity of air, which is a factor that causes the building to have high heat accumulation (Al-Jabri et al. 2005). Therefore, the development of novel wall systems with low thermal conductivity must be developed by improving the materials used in the production of concrete blocks or interlocking blocks.

Currently, building materials are expensive and becoming more consistently expensive, especially materials that are environmental friendly and high-quality materials, including the cost of design and construction. In the long run, however, the recycling of waste materials will help reduce costs. It can also reduce pollution in the environment as well as increase energy savings (Al-Jabri et al. 2005). Thailand is an agricultural country where rice is mainly grown, and is one of the top exporters in the world. Rice is produced in every region, especially the central part of the country. Each year, approximately 25.9 million tons of rice can be produced, resulting in rice straw being agricultural waste of about 3 times the amount of rice, representing 87.57 million tons. In addition, rice straw has been used in many ways such as forage, mushroom cultivation, straw wreath making, flowers, in the paper-making industry and renewable energy. Still, large amounts of straw remain un-used. It is estimated that about one third of the rest is burned (Srihabutra et al. 2017).

In the past, many researchers used waste materials for benefit by improving the properties of the materials used in construction, especially wall systems. The waste materials such as rice straw and rice husk ash are called biomass. The properties of the insulation from biomass are important to develop better materials. The characteristics of the blocks have been designed to be inside a hole to prevent heat into the building because the thermal conductivity of concrete is higher than the heat conductivity of the air. On the other hand, the brick is a small rectangular and a solid block typically made of fired or sun-dried clay for used in the masonry in fill wall. Therefore, making a block wall with holes or gaps can reduce the temperature in the building. However, the physical design of masonry alone is not enough to help reduce the temperature that enters the buildings in Thailand because it is a tropical country. Thus, the concept of

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bringing natural products into the manufacture of block wall to reduce thermal conductivity is appealing (Khedari et al. 2016; Nankongnab et al. 2009; Ekasilp and Boonthanomwong 2014). However, adding large amounts of natural materials for block walls will also result in the compressive strength of the material being lowered, which may affect its use. Therefore, it is preferable to use cementitious materials with basic properties similar to cement to replace or add for better support in order to improve the load carrying capacity of the material (Klabprasit et al. 2008). The properties of the binder must have a chemical composition that can cause pozzolanic reactions. According to Ramjan et al. (2017), rice husk ash contains SiO₂, Al₂O₃ and Fe₂O₃, which are important components in the pozzolanic reaction. This is consistent with the studies by Klabprasit et al. (2008), which showed that the appropriate amount of SiO₂ and Al₂O₃ could increase the strength of certain materials. In this regard, mixing rice husk ash in concrete not only helps to improve the concrete properties to be more powerful, but also helps the concrete to be more durable. According to preliminary studies, the ash used in the mixture has good properties in terms of being extremely lightweight and having the main chemical composition that helps to create calcium silicate hydrate (CSH) binder for strength.

The raw rice husk is a by-product of rice milling. It is also a good fuel, resulting in the use of rice husk as fuel in the electricity generation industry. Rice husk ash is the waste from being used as fuel in biomass electricity generation, which creates a large amount of rice husk ash as waste. Research concerning the use of rice husk ash will help to recycle waste as well as reduce waste. Therefore, this research has the idea to use local materials such as rice straw and rice husk ash as components in the production of interlocking blocks. It comprises an innovation in the development of materials that have high heat resistance and improved material properties. It also increases the utilization of rice straw, thereby reducing the elimination of rice straw from incineration, reducing the increase of pollution, and creates added value to waste materials for generating income for the community.

2. Materials and methods

2.1 Materials

The raw materials used are, Type 1 ordinary Portland cement (OPC), lateritic soil (LS), sand (SN), rice straw (RS) and rice husk ash (RHA). These materials are used in mixing the production of interlocking blocks for the study of their physical properties, sound absorption, and heat resistance. The Type 1 cement conforms to the Thai Industrial Standard TIS 15-2547 (TIS 2004), and has a specific gravity of 3.2, average particle size by volume of 23.32 μm and specific surface area 610 m²/kg. The main chemical components are calcium oxide (CaO) and silicon dioxide (SiO₂) at 65.5 and 21.0%, respectively, as shown in Table 1 (Intaboot et al. 2018). Rice husk ash [shown in Fig. 1(a)] was acquired from a biomass power plant in Chainat Province, with drying done through sieve No. 30 (0.59 mm). It has a specific gravity of 2.24, average particle size of 39.34 μm by volume (Fig. 2) and specific surface area of 370 m²/kg. The main component is 93.0% silicon dioxide (SiO₂), as shown in Table 1 (Intaboot et al. 2018).

Lateritic soil, which is shown in Fig. 1(b), is a kind of soil found in Suphan Buri Province It was passed through sieve No. 4 (4.75 mm) and the resulting particle size distribution is shown in Fig. 2. The specific gravity is 2.60. Sandy soil is natural river sand sieved with sieve No. 4 (4.75 mm). It has a specific gravity of 2.65 and the particle size distribution shown in Fig. 2. Rice straw is the part of the rice plant that is left after harvesting, which can be minced, chopped, and ground into smaller pieces as shown in Fig. 1(c), allowed to cool in the sun to reduce the moisture, then passed through sieve No. 4 (4.75 mm).

![Fig. 1 Raw materials.](a) Rice husk ash  
(b) Lateritic soil  
(c) Rice straw
2.2 Mix proportion
The production of interlocking blocks started by determining the ratios for the soil, cement and sand in the mix, which was 5:1:1 by weight (this is the ratio used by the factories in Suphan Buri). This was followed by adding rice husk ash and rice straw to various mixture rates. The rice husk ash will increase at the ratio of 10, 20, and 30% of the cement weight. Rice straw increases at a ratio of 0, 1, 2, and 3% by cement weight. For suitability, the rice straw is a lightweight material and it should be used no more than 3% by cement weight because the strength of interlocking block is decreased (Nankongnab et al. 2009; Srihabutra et al. 2017). The amount of water is used at 30% of the lateritic soil weight, which is standard in manufacturing interlocking blocks in Thailand (Intaboot 2018) as shown in Table 2. After the material preparation is complete. The cement, sand, lateritic soil, and biomass were mixed together in the mixer shown in Fig. 3(a) and the mixture was formed into interlocking blocks by the hydraulic press shown in Fig. 3(b).

2.3 Tests
Unit weight, porosity and water absorption were tested in accordance with ASTM C138-92 (ASTM 2002) and ASTM C20 (ASTM 2000), respectively. Interlocking blocks of size 120 × 100 × 250 mm shown in Fig. 3(c) at the age of 28 days, cured in the air at a temperature of 37°C and 62% relative humidity, were used for the tests. The 28-day compressive strength was tested according to the Thai Industrial Standard TIS 109-2517 (TIS 1974). Before testing, the samples were capped at both ends with plaster capping. The reported results are the averages of 5 samples. The thermal conductivity coefficients and sound absorption were tested at Kasetsart University in accordance with ASTM C518 (ASTM 2004) and ISO 10534-2 (ISO 1998).

3. Results and discussion
3.1 Effects of compressive strength, unit weight, water absorption and porosity of interlocking blocks
The results for the compressive strength, unit weight, water absorption and porosity of interlocking blocks are shown in Table 3. In the mixture S0 group (without rice straw), the compressive strength tended to increase when

| Mix    | Lateritic soil (kg) | Cement (kg) | Sand (kg) | Water (kg) | Rice straw | Rice husk ash |
|--------|---------------------|-------------|-----------|------------|------------|---------------|
| S0A10  | 5                   | 1           | 1         | 1.5        | 0          | C × 10%       |
| S0A20  | 5                   | 1           | 1         | 1.5        | 0          | C × 20%       |
| S0A30  | 5                   | 1           | 1         | 1.5        | 0          | C × 30%       |
| S1A10  | 5                   | 1           | 1         | 1.5        | C × 1%     | C × 10%       |
| S1A20  | 5                   | 1           | 1         | 1.5        | C × 2%     | C × 20%       |
| S1A30  | 5                   | 1           | 1         | 1.5        | C × 3%     | C × 30%       |
| S2A10  | 5                   | 1           | 1         | 1.5        | C × 1%     | C × 10%       |
| S2A20  | 5                   | 1           | 1         | 1.5        | C × 2%     | C × 20%       |
| S2A30  | 5                   | 1           | 1         | 1.5        | C × 3%     | C × 30%       |
| S3A10  | 5                   | 1           | 1         | 1.5        | C × 1%     | C × 10%       |
| S3A20  | 5                   | 1           | 1         | 1.5        | C × 2%     | C × 20%       |
| S3A30  | 5                   | 1           | 1         | 1.5        | C × 3%     | C × 30%       |
However, as shown in Table 3, it was found that compressive strength tended to decrease in all groups of rice straw when mixed with rice straw. The mixture S1A10, S1A20, and S1A30 (with 1% rice straw addition) had compressive strengths of 5.02, 4.67, and 4.36 MPa, respectively. The mixture S2A10, S2A20, and S2A30 (2% rice straw addition) had compressive strengths of 4.38, 3.59, and 3.20 MPa, respectively. Meanwhile, the mixture S3A10, S3A20, and S3A30 (3% rice straw addition) had compressive strengths of 4.05, 3.19, and 2.85 MPa, respectively. When combined with rice straw, the interlocking blocks will become more porous, in accordance with the observations of Srihabutra et al. (2017) and Nankongnab et al. (2009), who found that the compressive strength of interlocking blocks will decrease as rice straw increases. However, the compressive strength still passed the requirements of the Thai Industrial Standard (TIS 1990), which specifies that the compressive strength of non-load-bearing concrete blocks must not be less than 2.5 MPa. Thus, if the quantity of rice straw and rice husk ash is excessive in the mix, it means the interlocking blocks cannot be used. In addition, the quality will not meet the above standard either.

**Table 3** Compressive strength, unit weight, water absorption and porosity of interlocking blocks.

| Mix   | Compressive strength (MPa) | Unit weight (kg/m³) | Water absorption (%) | Porosity (%) |
|-------|----------------------------|--------------------|---------------------|--------------|
| S0A10 | 5.06                       | 1860.87            | 16.69               | 26.81        |
| S0A20 | 5.22                       | 1913.04            | 16.59               | 26.50        |
| S0A30 | 5.79                       | 1991.30            | 16.09               | 26.40        |
| S1A10 | 5.02                       | 1960.87            | 17.99               | 28.30        |
| S1A20 | 4.67                       | 2004.35            | 17.24               | 27.77        |
| S1A30 | 4.36                       | 2060.87            | 17.00               | 27.11        |
| S2A10 | 4.38                       | 1917.39            | 18.90               | 2800.        |
| S2A20 | 3.59                       | 1965.22            | 17.62               | 27.85        |
| S2A30 | 3.20                       | 2000.00            | 17.36               | 27.73        |
| S3A10 | 4.05                       | 1769.57            | 20.14               | 29.30        |
| S3A20 | 3.19                       | 1852.17            | 19.54               | 28.91        |
| S3A30 | 2.85                       | 1891.30            | 17.39               | 28.70        |

The result of water absorption and porosity is shown in Fig. 4. The increasing of rice straw causes the interlocking blocks to have an increased rate of average water absorption. For the groups S0, S1, S2, and S3, the average water absorption rates are 16.46, 17.41, 17.96 and 19.02%, respectively. The rice straw has a hollow appearance, as shown in Fig. 6. (Srihabutra et al. 2014). If used in large quantities, it creates cavities in the interlocking blocks, resulting in a large amount of water absorption. However, when increasing the amount of rice husk ash in all groups of rice straw addition S0, S1, S2, and S3, the percentage of porosity in the interlocking block decreases, as shown in Fig. 7. This is because the
increased rice husk ash results in insertion in the gap and reaction with the cement, causing the gel to fill the gap, which results in reduced porosity and reduced water absorption. In the groups of S0, S1, S2, and S3, water absorption decreased by 3.59, 5.50, 8.15 and 13.65%, respectively. However, the water absorption of 25% in this study is lower than that specified in TIS 58-2533 (TIS 1990).

The relationship between the water absorption and porosity of interlocking blocks is shown in Fig. 8. It was found that water absorption and porosity are directly related, meaning that when the porosity of the material increases, it will also increase water absorption. The relationship is also a linear regression according to other research (Intaboot et al. 2018; Kearsley and Wainwright 2001). Therefore, the linear equations obtained from this experiment can represent predictive analysis between the two variables.

3.2 Effects on thermal conductivity and sound absorption of interlocking block

The thermal conductivity (K) of the interlocking blocks was tested from Kasetsart University according to ASTM C518 (ASTM 2004). It was found that the interlocking blocks had thermal conductivity varying between 0.16 and 0.23 W/m.K. Similar studies by Intaboot (2018) found that the thermal conductivity of interlocking blocks made from sludge and water hyacinth was between 0.19 and 0.24 W/m.K. This is very low thermal conductivity for materials that have similar weight. From previous studies, it was found that the thermal conductivity was in the range of 0.25 to 1.00 W/m.K in other building materials such as refractory bricks, bricks block mix with fly ash, hollow concrete blocks, etc. with unit weights of 720 to 2000 kg/m³ (Chindaprasirt et al. 2015).

From the test results shown in Fig. 9, it was found that the thermal conductivity will decrease when the interlocking blocks have increased the rice straw, following the amount of fibre increase. The rice straw has a fibre characteristic that, when rice straw fibres increase, it results in more cellulose inside the material. This cellulose makes the material an insulator, which can reduce the thermal conductivity (Nankongnab et al. 2009). This is consistent with the study of Khedari et al. (2005), who found that the thermal conductivity decreases with the increase of natural fibres. In addition, the increase in rice husk ash will also reduce the thermal conductivity. The increase of rice husk ash at the rate 10, 20, and 30% in the groups of S0, S1, S2, and S3, the thermal conductivity will decrease by 4.68, 3.70, 3.53 and 2.27%, respectively. Rice husk ash is classified as a biomass material; if mixed with a construction material such as brick for masonry, it helps to reduce heat in the building. Consistent with the study of Paopongpaiboon et al. (2019), it was found that the biomass ash has a low thermal conductivity when mixed in interlocking blocks, thus resulting in good insulation. However, the reduction of...
thermal conductivity obtained from the increase of rice husk ash is still less than the reduced thermal conductivity due to the increase of rice straw, as shown in Fig. 9. This is because rice straw causes the interlocking blocks to have high porosity. From previous research studies, it was found that materials with high porosity resulted in lower thermal conductivity (Kroehong et al. 2016; Vaji et al. 2013). When considering the relation between porosity and thermal conductivity, as shown in Fig. 10, it was found that the increase in porosity or gaps in the material will reduce the thermal conductivity, which is according to the reports of Torkittikul et al. (2017). It was also found that the decrease in thermal conductivity will be a linear decrease as the porosity increases, which is consistent with this study.

The tests to determine the sound absorption coefficient ($\alpha$) was conducted in accordance with ISO 2-10534 (ISO 1998). The test set consists of an impedance tube with two microphones to test the sound absorption coefficient of interlocking blocks mixing rice straw and rice husk ash. From previous studies, it was found that the ground rice husk ash used in the mixture of cement blocks in the ratio of 20% showed good sound absorption properties, meaning it is suitable for use in order to increase the efficiency of sound absorption (Lertwattanaruk and Makul 2014). The rice straw is considered a porous material as it has interior spaces with diameters of less than 1 mm, which is much lower than the size of sound wavelengths. Thus, these materials are intermediaries that cause energy loss and good sound absorption (Viriya 2001). Therefore, this study used interlocking block with 20% rice husk ash and 0, 1, 2, and 3% rice straw mixed in S0A20, S1A20, S2A20, and S3A20. The result is shown in Fig. 11.

From the tests to identify the sound absorption coefficient ($\alpha$) of the interlocking blocks at frequencies of 250 HZ, 500 HZ, and 2000 HZ, it was found that the interlocking blocks with rice straw in the ratio of 0 and 1% have good coefficient of sound absorption properties in the low frequency (under 1000 HZ). The good sound absorption coefficient at this range is 0.384 at the frequency of 500 HZ in the mixture S1A20. The good sound absorption coefficient at this range is 0.384 at a frequency of 500 HZ in the mixture S1A20. However, the mixture with rice straw in the ratios of 2 and 3% will have the best sound absorption coefficient when the frequency is higher (more than 1000 HZ). The maximum sound absorption coefficient was 0.763 at the frequency of 2000 HZ in the S3A20 mixture. From the test results, it can be concluded that the interlocking blocks that contain less rice straw mixture (ratio of 0 and 1%) will have sound absorption properties similar to membranes absorber. The membrane absorber is a good sound absorbing material in the low frequency. Further, when the interlocking blocks contain more rice straw (2 and 3 %), they will have sound absorption properties similar to fibre or porous dissipative absorbers. When the sound hits the air molecules, these materials will cause shaking in the gaps of porous materials. The vibrations of the air molecules will cause a significant loss of energy when the sound is high at the impact frequency (Viriya 2001). Therefore, it helps to absorb sound well at higher frequencies when considering the ability for sound absorption or the noise reduction coefficient (NRC), which represents the ability to absorb the sound of the material. The NRC is the average of the sound absorption coefficient at every frequency. It was found that the mixture of S0A20, S1A20, S2A20, and S3A20 had NRC values of 0.175, 0.251, 0.2758 and 0.356, respectively. This indicates that the more porous the material, the better ability for sound absorption.

Further, the interlocking blocks are classified as having moderate efficiency in sound absorption (NRC between 0.2 and 0.4) (Viriya 2001).
4. Conclusions

This study involved innovation in the production of interlocking blocks mixing rice straw and rice husk ash for sound absorption and thermal conductivity. It starts from the study of the basic properties of the material, including the compressive strength, weight units, water absorption and porosity. After that, the effects of heat conduction and sound absorption were assessed. The study results can be summarized as follows:

(1) The compressive strength was between 2.8 and 5.8 MPa and decreased as the amount of rice straw increases. The compressive strength passed the requirement of the Thai Standard TIS 58-2533 (TIS 1990) for hollow non-load bearing concrete masonry units. The unit weight increased with the increase of rice husk ash because the rice husk ash has a smaller particle size than lateritic soil, and can infiltrate into cavities to increase density. Further, rice straw increase causes density decrease, mainly because the fibre-type material causes the interlocking blocks to have lower weight unit.

(2) Increasing the amount of fibre materials increases the porosity of the interlocking blocks and consequently, the water absorption. When rice husk ash is added, however, the porosity is decreased and the water absorption is decreased. The rice husk ash helps the soil to have better mixing and more density, resulting in reduced water absorption. However, the water absorption meets the requirement of the Thai Standard TIS 58-2533 (TIS 1990).

(3) The thermal conductivity of the interlocking blocks decreases as the rice straw increases and also decreases slightly as a result of the increase in rice husk ash. This is because rice straw and rice husk ash are natural fibres, whose porosity and high insulation results in low thermal conductivity, making the blocks suitable for development into construction materials.

(4) The sound absorption of the interlocking blocks can be divided into 2 sound frequency ranges. The low frequency range of the blocks with low fibre composition has good sound absorption coefficient. However, those with high fibre content have the best sound absorption coefficient in the high frequency range. If considering the reduction of noise, it was found that the material with the highest porosity has the best sound absorption value.

(5) It is concluded from this study that the interlocking blocks mixing rice straw and rice husk ash are suitable for further development as an innovation in construction materials that could be useful for commercial development. The findings could also aid in the development of construction engineering materials in the future.

In this study, only a preliminary investigation was carried out by trying to use leftover natural materials in a more useful way. However, natural materials can degrade over time, especially when coming into contact with moisture, chemicals, and temperature. Therefore, it is necessary in future studies to use materials that are highly durable and difficult to degrade so that they can be developed and actually be constructed in the future.

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