THE DEVELOPMENT OF CELLULAR LIGHTWEIGHT CONCRETE MADE FROM OIL PALM FIBER AND BIOCHAR

Panisa Sangkeaw [1], Withit Pansuk [2]*, Rungrawee Wattanapornprom[3]
[1,2,3] Department of Civil Engineering, Chulalongkorn University, Bangkok, Thailand
*Corresponding author; e-mail: deempanisa@outlook.co.th

Abstract
Oil Palm Fiber (OPF) and Biochar (BC) are the wastes from Agro-Industry in Thailand. Every year, a large amount of OPF and BC are disposed to a landfill site. The proper method to manage these wastes remains unclear. Cellular Lightweight Concrete (CLC) is one of the most significant types of concrete used for construction purposes due to its various advantages. Thus, the propose of this study is to find a better process to recycle the waste properly by using OPF and BC in CLC. In this study, the CLC specimens with OPF and BC were prepared. The specimens are divided into four groups. The first group is the normal CLC with water to cement ratio (W/C) 50 %. The second is CLC combined with OPF 2, 4 and 6 %. The third is the CLC mixed with BC 5, 10 and 15 %. The fourth is CLC combined with 1.5 % OPF and 10 % BC by weight of sand. The specimen's compressive strength, dry density, water absorption, and heat transfer properties were evaluated. The experimental results showed that adding OPF and BC in the proportions, the specimens tended to have higher dry density and compressive strength due to the less air content and filler effect in CLC. Besides, OPF and BC specimens have less water absorption. For the heat transfer properties, CLC with OPF and BC has a better quality of thermal insulation. The studies showed that OPF and BC could be utilized in improving the properties of the normal CLC if added with a proper amount.

Keywords:
Cellular Lightweight Concrete (CLC); Oil Palm Fiber (OPF); Biochar (BC); Thermal Insulation; Compressive Strength

1 INTRODUCTION

Cellular Lightweight Concrete (CLC) is a standard material used in construction work, such as non-loading walls, and heat-insulated light wall panel, due to its various advantages. CLC is able to use as thermal insulation materials which can save energy from using air condition in the building. CLC can be produced by creating foam or air bubbles and then mixed with mortar (Nagesh Mustapure, 2016).

Oil Palm Fiber (OPF) and Biochar (BC) are the wastes from Agro-Industry in Thailand. Every year, a large amount of OPF and BC are disposed to a landfill site. The proper method to manage these wastes remains unclear.

Based on the previous research, OPF has been utilized as an ingredient in plain concrete to improve mechanical properties such as compressive strength and flexural strength. By replacing the cement with palm fiber 0.5 - 1.5 %, the compressive strength 5.6 - 43.2% and the bending strength increased 11.8 - 45.6% (Mahyuddin Ramli, 2010). In addition, it has been reported that plaster concrete with OPF has lower thermal conductivity compared to the normal plaster concrete (Amina Djoudi, 2014).

Biochar (BC) is another material that can help in reducing the thermal conductivity in concrete. From the previous research, by Ithaka Institute, Switzerland, showed that the buildings which using the materials containing BC can maintain the temperature inside and the concrete with BC has lower thermal conductivity (Hans Peter Schmidt, 2013).

As a result, the purpose of this study is to find a better process to recycle the waste properly by using OPF and BC in the standard construction materials.

2 EXPERIMENTAL METHODOLOGY

2.1 Materials Preparations

1. Type I ordinary Portland cement conforming to ASTM C150 was used in this study.
2. Fine aggregate is the river sand with a fineness modulus equal to 2.06 and Water absorption 0.68.
3. Synthetic Foam agent is prepared according to ASTM C796-04 by mixing synthetic foam agent with water at a ratio of 1:20 and control density 32-64 kg/m^3
4. OPF in the experiment was taken from the oil palm industries in Southern Thailand. OPF has an average size of 2-3 cm. The original fiber from the factory was dehydrated and compacted into the cube shape. Consequently, before using the fiber in the CLC mix, the fiber must be soaked in the water at least 24 hours to make the fiber soft and loosen. After soaking the fiber in the water, fibers were dried with a towel or paper and placed at room temperature for another 1-2 days. The physical shape of the OPF is shown in figure 1.

5. BC was also taken from Southern Thailand. Before using, BC was spread on the plate and placed at room temperature for about one day to reduce the moisture. The physical shape of the BC is shown in figure 2.

Fig. 1: Oil Palm Fiber (OPF)

Fig. 2: Biochar (BC)

2.2 Mix proportions

The CLC mix proportions in this study were designed by using the different percent of OPF and BC. The OPF and BC were used as the replacement of fine aggregate, water to cement ratio (W/C) 50% and sand to cement ratio (S/C) of 1 and 1.5. The mix proportions of the CLC is shown in table 1 and 2.

Table 1 Proportions of CLC mixtures per m^3(S/C = 1)

Mix no.	Mix proportions (kg)					foam (litre)
	cement	sand	water	OPF	BC	
1	419	419	210	-	-	500
2	419	410	210	8	-	500
3	419	402	210	17	-	500
4	419	394	210	25	-	500
5	419	398	210	-	21	500
6	419	377	210	-	42	500
7	419	356	210	-	63	500
8	419	371	210	6	42	500
9	335	297	168	6	42	600

Table 2 Proportions of CLC mixtures per m^3 (S/C = 1.5)

Mix no.	Mix proportions (kg)					foam (litre)
	cement	sand	water	OPF	BC	
1	362	543	181	-	-	500
2	362	532	181	11	-	500
3	362	521	181	22	-	500
4	362	510	181	33	-	500
5	362	516	181	-	27	500
6	362	489	181	-	54	500
7	362	462	181	-	81	500
8	362	481	181	8	54	500
9	290	385	145	8	54	600

2.3 Specimens and Test

1. Scanning Electron Microscope (SEM)

   The microstructure of CLC was investigated by using Scanning Electron Microscope (SEM). The specimens, size smaller than 10 mm, were taken from the hardened CLC. Specimens were submerged directly into liquid nitrogen for 5 minutes then evacuated under pressure of 0.5 N/m2 at temperature of -40 ºC for 1-2 days. After that, check the internal structure of CLC by using the SEM machine (Khamphee Jitchaiyaphum, 2011).

2. Dry Density Test

   The dry density test was conducted in accordance with the BS EN12390-7:2009 standard. The test specimens, size 15 x 15 x 15 cm^3 shown in Fig. 3, were prepared. Tolerances of each specimen was not exceeded 1 mm. and then dried in an oven at 105±5 °C for 24 hours. The test specimens were removed from the oven and placed at room temperature, approximately 1 - 2 hours. Then, the weight and the dimension of the specimen were recorded and the volume of the specimen was calculated (BS EN12390-7, 2009).

Fig. 3: Specimens size 15x15x15 cm^3

3. Compressive Strength test

   For the compressive strength test, cubic concrete specimens 15 × 15 × 15 cm^3 shown in Fig.3,were prepare and cured with clean water for 14 and 28 days. After curing, the specimens were taken from the water and left at room temperature for about 1 day to allow specimens to dry before testing. Apply and increase the load continuously at a nominal rate within the range 0.02 N/mm^2 s to 0.04 N/mm^2.s until no greater load can be sustained (BS1881-Part116, 1983).

4. Water absorption test

   The specimen size 15 x 15 x 15 cm^3 shown in Fig.3 were prepared. Place the three specimens in the drying oven. Further specimens shall not be placed in the same oven during the drying process and there shall be free access of air to all surfaces of the specimens. Weigh each specimen and immediately completely immerse in the tank with its longitudinal axis horizontal. Leave the specimens immersed in the water. Remove each specimen, shake it to remove the bulk of the water and dry it with a cloth as rapidly as possible until all free water is removed from the surface. Weigh each specimen (BS1881-Part122, 1983).

5. Splitting Tensile Strength test

   Cube test specimens of 15x15x15 cm^3 shown in Fig.3 were casted. After curing, place the test specimen in the centering jig with packing strips and loading pieces carefully positioned along the top and bottom of the plane of loading of the specimen. Then, apply and increase the load continuously until failure.(BS1881-Part117, 1983).

6. Heat Transfer Test

   Heat transfer test was set as shown in Fig.4 The specimens for the test is 30x30x8 cm^3 slab as shown in Fig.5. Before testing, place the test specimen at room temperature for 1-2 days to allow the specimens to have similar temperatures throughout the slab. Then, draw the gridline on the specimen's surfaces. After that, place the specimen in front of the spotlight. Measure the temperature, T_{in}, from position 1-9, on the specimen's surface by using the infrared Thermometer every 2 minutes until it reaches 1 hour. (Modified from ASTM C518, 2010).

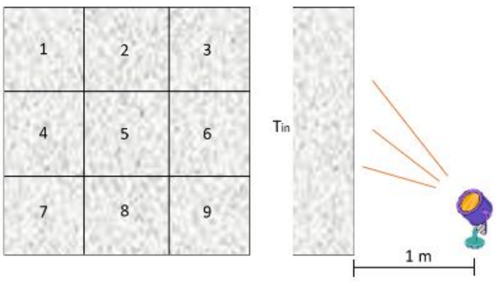

Fig. 4: Heat Transfer test

Fig. 5: Specimens size 30x30x8 cm^2

3 EXPERIMENTAL RESULTS

3.1 Scanning Electron Microscope (SEM)

The internal structure of CLC was checked by using scanning electron microscope (SEM). It was found that the specimen with OPF has smaller size of air void which cause in increasing the density of the CLC. The SEM results are shown in Fig. 6 and 7.

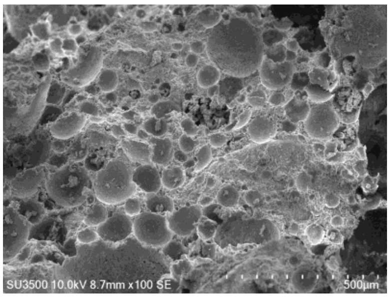

Fig. 6 : normal CLC foam 50%

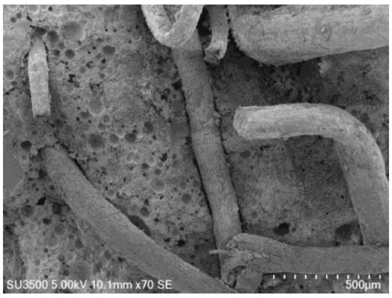

Fig. 7: CLC with OPF foam 50%

However, when BC in the mix, BC added did not reduce the size of the porosity. Moreover, BC is the porous media which could help in reducing heat transfer in CLC. The SEM pics of CLC with BC is shown in Fig. 8.

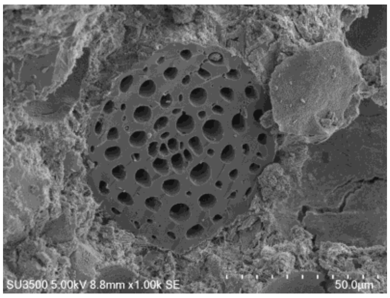

Fig. 8: CLC with BC foam 50%

Fig. 9 showed that, in the CLC with OPF and BC, OPF and BC are well distributed within the test specimens.

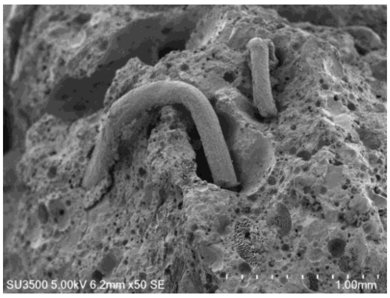

Fig. 9: CLC with OPF and BC foam 50%

3.2 Dry Density

Fig. 10 shows the dry density of CLC combined with OPF 2, 4 and 6 % by weight of sand compare with normal CLC. The results showed that, when the amount of OPF in the mixture is increased, the dry density of the specimen is also increased. When added the OPF in CLC mixture, the foam tends to collapse. The air void inside the CLC specimen is reduced, resulting in a denser concrete texture.

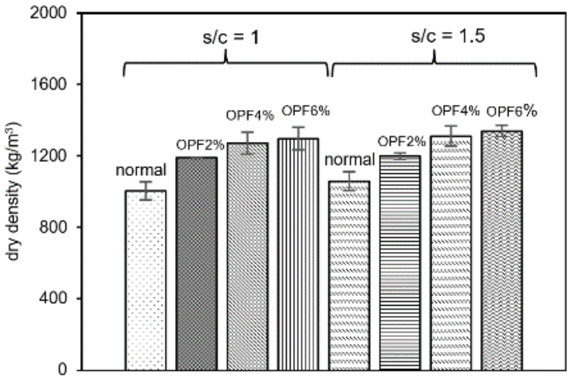

Fig. 10: Dry Density of CLC with OPF

Fig. 11 shows the dry density of CLC combined with BC 5, 10 and 15 % by weight of sand compare with normal CLC. The results showed that when the amount of BC in the mixture increased, the dry density is slightly increased. The BC's internal structure has a small porosity. Therefore, when mixed the BC with CLC, the density did not change and the foam did not collapse.

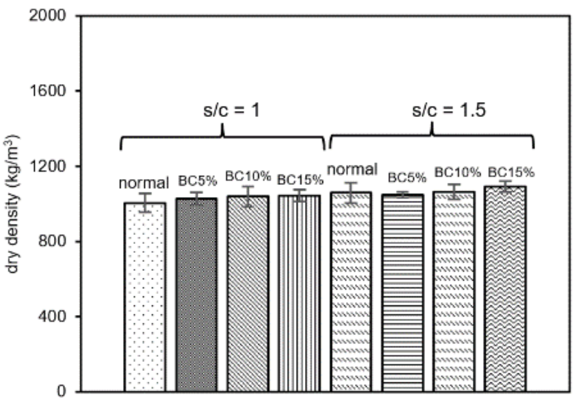

Fig. 11: Dry Density of CLC with BC

Fig. 12 shows the dry density of CLC combined with 1.5 % OPF and 10% BC by weight of sand. The results showed that when adding OPF and BC, dry density of concrete was higher than that of normal CLC. To control the density of the CLC, the foam ratio should be increased in the mix proportions.

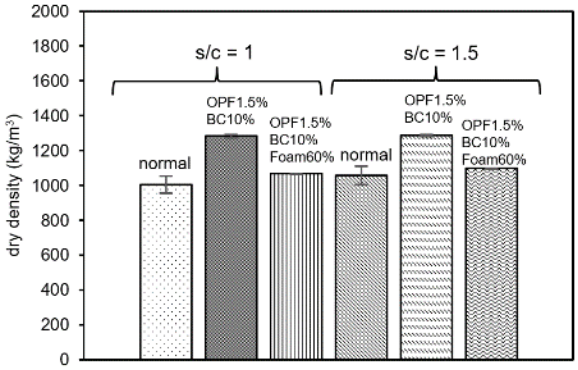

Fig. 12: Dry Density of CLC with OPF and BC

3.3 Compressive Strength

Fig. 13 and 14 show compressive strength at 14 and 28 days of CLC combined with OPF 2, 4 and 6 % compared with normal CLC. When, the amount of OPF in the mixture increased, specimens tend to have higher compressive strength because the air void in CLC concrete was reduced.

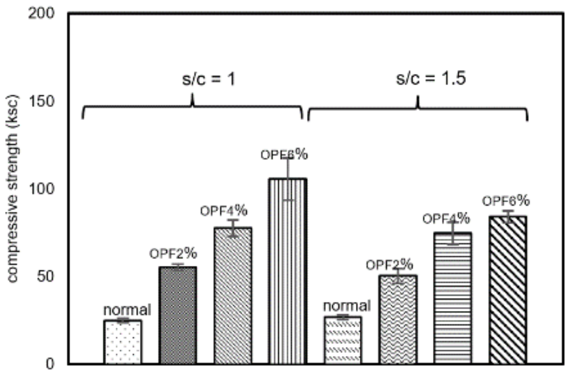

Fig. 13: Compressive Strength of CLC with OPF at 14 days

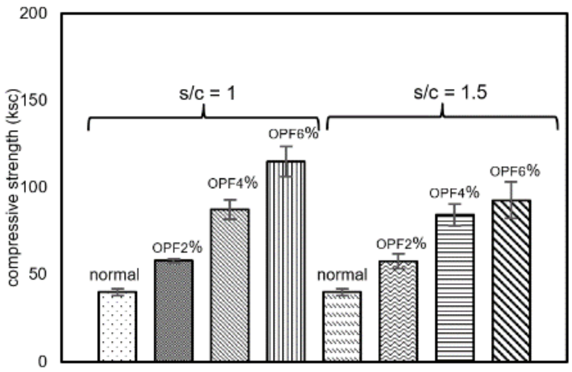

Fig. 14: Compressive Strength of CLC with OPF at 28 days

On the other hands, when adding the BC in CLC, the compressive strength is also increased. Fig. 15 and 16 shows compressive strength at 14 and 28 days of CLC combined with BC. The reason is due to shap of BC which can interlocking inside the specimens or fill gaps between cement and fine sand in some parts. BC also has water retention and internal curing properties. Thus, during the early hydration process, the water from the BC is gradually released, and the cement particle can have a higher degree of hydration. For this reason, CLC with BC can have a better strength development compare to the normal CLC (Hyun Do Yun, 2012).

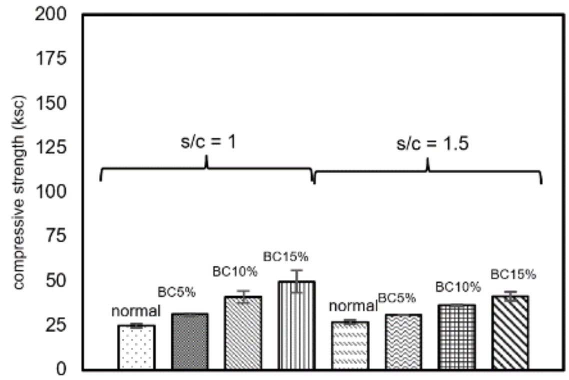

Fig. 15: Compressive Strength of CLC with BC at 14 days

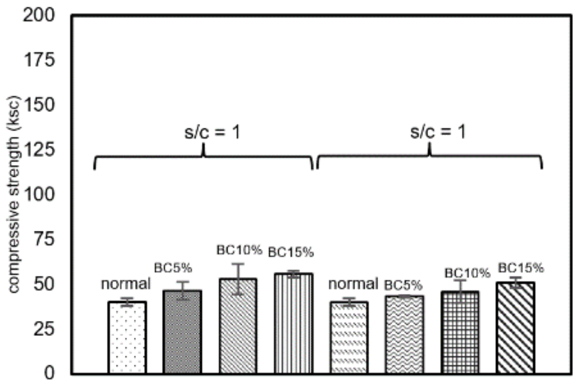

Fig. 16: Compressive Strength of CLC with BC at 28 days

Fig. 17 and 18 shows compressive strength at 14 and 28 days of CLC combined with OPF and BC 1.5 and 10% respectively. The combination of OPF and BC in the mixture resulted in higher compressive strength compared to normal CLC, as OPF contributes to reducing the air void in the CLC. Moreover, BC acts like the filter between sand and cement in the CLC metrics. Thus, the CLC has higher compressive strength.

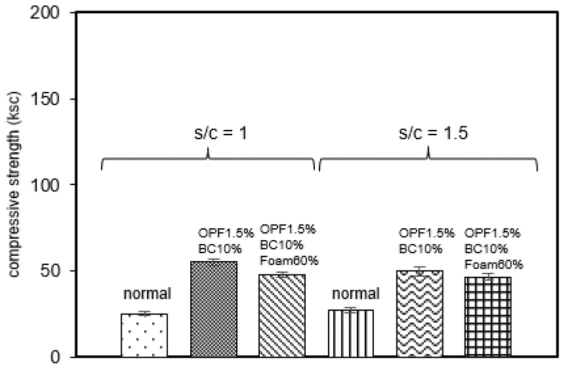

Fig. 17: Compressive Strength of CLC with OPF and BC at 14 days

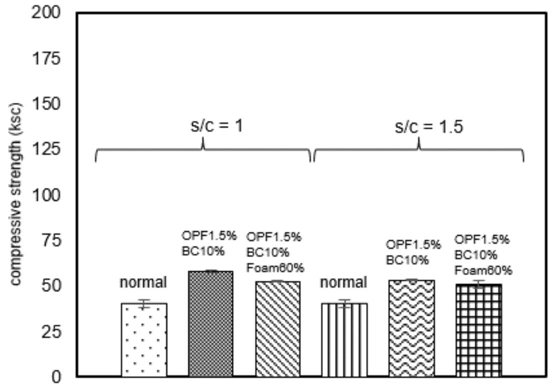

Fig. 18: Compressive Strength of CLC with OPF and BC at 28 days

3.4 Water Absorption

Fig.19 shows water absorption of CLC with OPF. The water absorption rate is reduced when increasing OPF. The OPF makes the concrete have less porosity and the density increases. Thus, the concrete can absorb less amount of water.

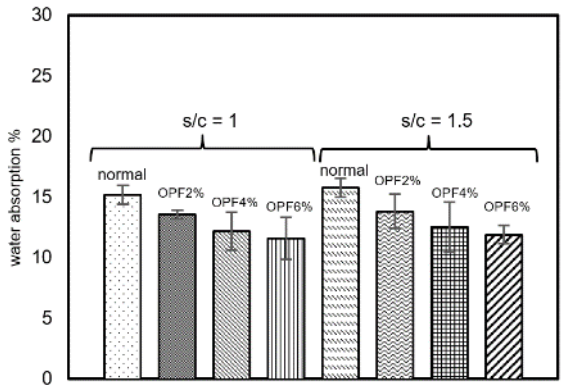

Fig. 19: Water Absorption of CLC with OPF

Fig.20 shows water absorption of CLC when mixing BC in the proportion. As a result, the water absorption rate of CLC is reduced. The BC powder can fill the gaps between sand and cement paste in the concrete. The connected porosity is decreased and less water amount can be penetrated into the specimens.

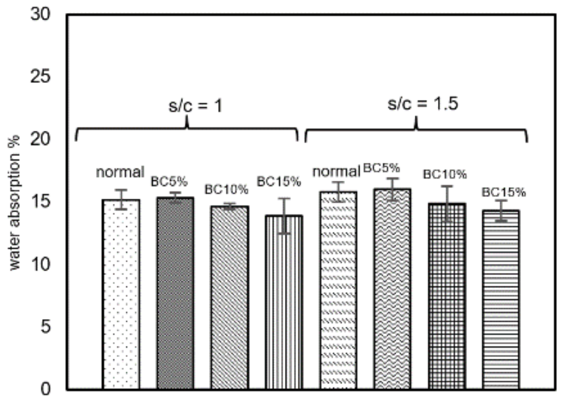

Fig. 20: Water Absorption of CLC with BC

Fig.21 shows water absorption of CLC combined with OPF and BC. When adding both OPF and BC in proportion, the water absorption rate of CLC is decreased.

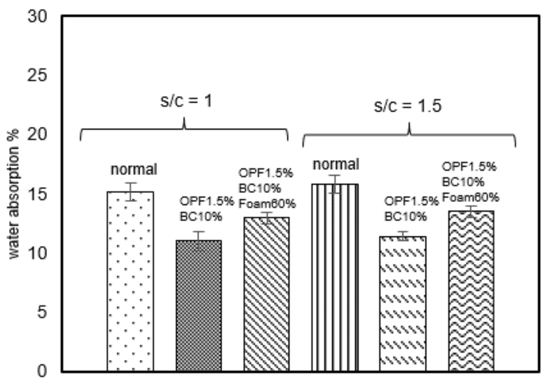

Fig. 21: Water Absorption of CLC with OPF and BC

3.5 Splitting tensile strength

Fig.22 shows splitting tensile strength of CLC with OPF From the result, the strength of the specimen is increased. The OPF inside the specimen helps in binding the crack and increase the tensile strength of CLC.

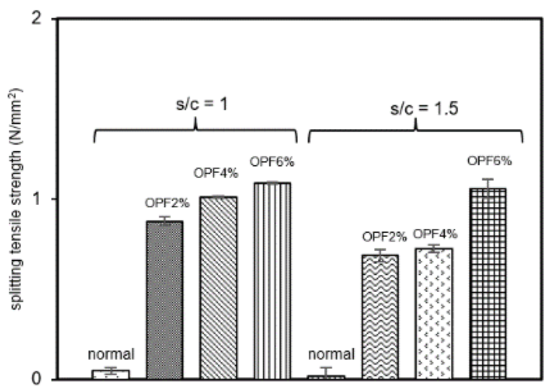

Fig. 22: Splitting Tensile Strength of CLC with OPF

Fig.23 shows splitting tensile strength of CLC contain BC. The splitting tensile strength of concrete is higher when adding higher amount of BC in the proportion . It may be due to the higher compressive strength and BC also has a flat shape which can increase the tensile strength.

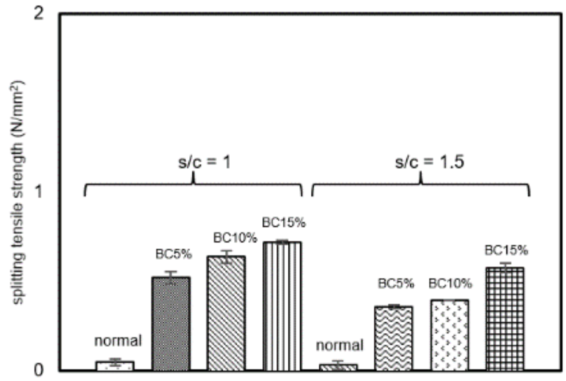

Fig. 23: Splitting Tensile Strength of CLC with BC

As a result, the splitting tensile strength of concrete is higher when putting OPF and BC in the mixture because OPF and BC help cement the crack and it is difficult to remove shows in Fig.24

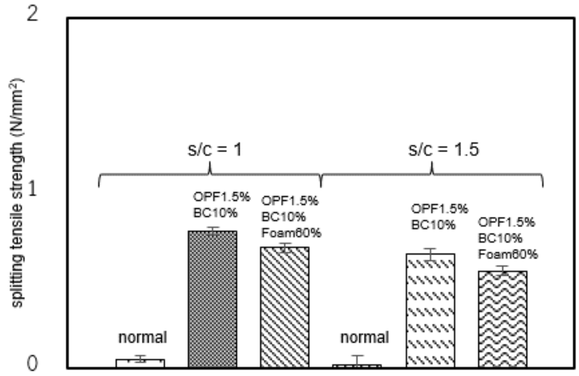

Fig. 24: Splitting Tensile Strength of CLC with OPF and BC

3.6 Heat Transfer

The specimen has a lower heat transfer when adding 2% of OPF in the mixture, however, In the 6% OPF specimen, the temperature is higher compared to the normal CLC. The reason is due to the OPF effects in reducing the foam in CLC. As a result, when the CLC has less air void, the heat can transfer to another side easier. The experimental results are shown in Fig.25 and 26

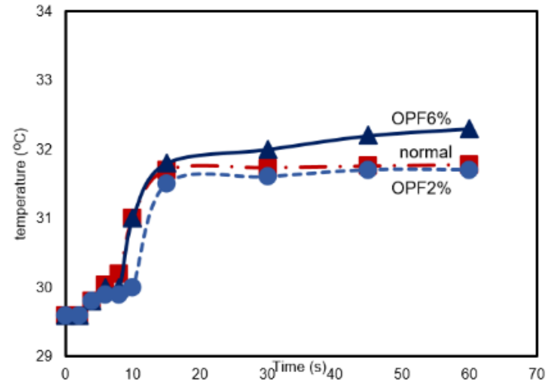

Fig. 25: internal surface temperature of normal CLC and OPF wall (s/c = 1)

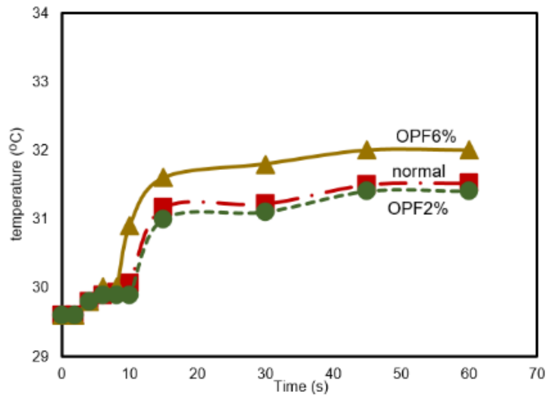

Fig.26: internal surface temperature of normal CLC wall and OPF (s / c = 1.5)

On the other hands, The CLC has a lower heat transfer when adding BC in the proportions, which means that it is more insulating compared to conventional CLC because BC particle is also a porous media and the temperature on the surface will increase when the surface of the specimens is attached to the spotlight. However, the heat cannot be transferred to another side due to the air void inside the specimen. The experimental results are shown in Fig.27 and 28

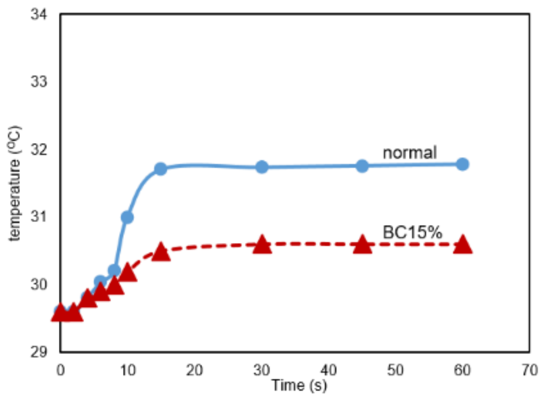

Fig. 27: internal surface temperature of normal CLC wall and BC (s / c = 1)

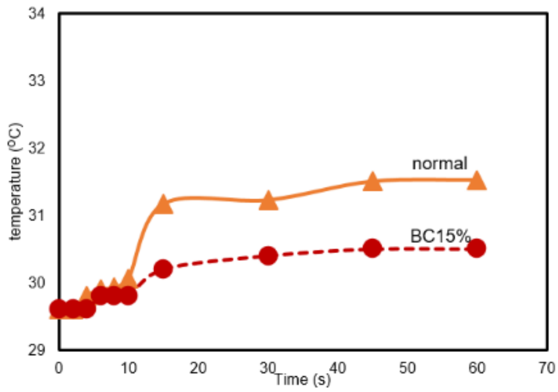

Fig. 28: internal surface temperature of normal CLC wall and BC (s / c = 1.5)

The last cases are the specimen combined with both OPF and BC in the mixture. The temperature in lower compared to the normal CLC. As a result shows in Fig. 29 and 30

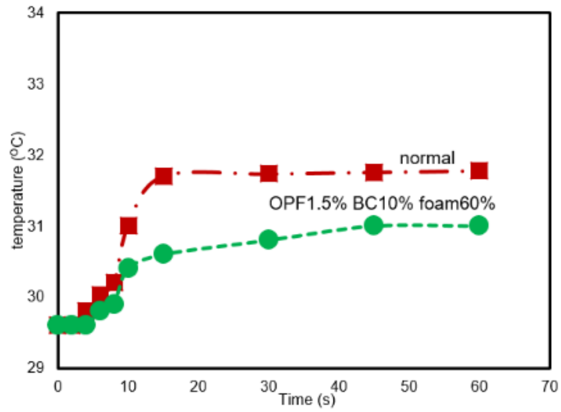

Fig. 29: internal surface temperature of normal CLC wall and OPF with BC (s / c = 1)

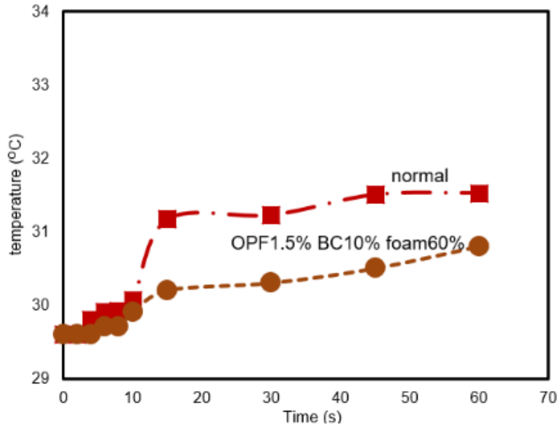

Fig. 30: internal surface temperature of normal CLC wall and OPF with BC (s / c = 1.5)

From the experimental results, The temperature is reduced significantly when added the OPF and BC in the specimen with similar density.

4 CONCLUSIONS

Adding OPF and BC in CLC in a proper amount can help in developing some quality of CLC as follow

1. When increasing proportion of OPF, the air void is decreased significantly. However, from SEM, when increasing the percentage of BC, the size and the amount of air void was not decrease.
2. When adding the OPF, the dry density is increased because the air void in CLC is reduced. On the other hands, BC particles, which has air void inside, did not affect the amount of air void. Thus, the dry density of CLC with BC is very close to normal CLC.
3. Mixing BC in the specimen can increase the compressive strength of CLC while maintain the density. The small particle of BC can fulfill the space between cement and sand. In addition, BC can absorb the water in itself and slowly release the water to CLC and improve hydration reaction at the early stage. However, mixing OPF in CLC, the compressive strength is also increase but due to the reduction of air void inside the specimen.
4. Water absorption of CLC trend to decrease a little bit when put OPF and BC because the CLC matrix become denser.
5. OPF and BC can increase splitting tensile strength of CLC.
6. BC's particle is porous and helps in reducing heat transfer of CLC

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