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A Study on Thermal Insulation of Cement Bricks Incorporate with Cellulose Fiber

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Abstract: Cement brick is one of the important and common building materials that widely being used in the construction industry. Common brick that being using in the construction industry nowadays are poor in thermal insulation. The objective of this study is to study the physical properties of cellulose fiber as added material in cement bricks, determine the mechanical properties of cement bricks containing cellulose fiber and lastly to evaluate the thermal performance for cement brick containing cellulose fiber compare with conventional cement bricks. The materials that being used is the cellulose fiber powder made from the bamboo plant with different percentage that added into the mixture of cement bricks. The test that has being carried out for this study is the density test, water absorption test, ultrasonic pulse velocity test, compressive strength test and thermal conductivity test. The specimens sample of 10% obtained the lower value of thermal conductivity with 0.153 W/m^{o}C and 0.161 W/m^{o}C. The density obtained is 2335.71 kg/m^3 and 2345.24 kg/m^3 with the compressive strength of 33.18 kN/m^2 and 41.04 kN/m^2. In conclusion, the value of thermal conductivity of all specimens has meet the standard requirements for thermal conductivity which is 0.69 W/m^{o}C. and below. The good production of bricks should obtain low thermal conductivity so that the building that use the bricks is cool in summer especially in the hot weather in Malaysia. The overall performance of the specimen bricks in this study that using cellulose fibre powder as addition materials in the production of cement bricks is encouraging as it is biodegradable, sustainable and biodegradable [12] and has the potential to improve for further development.

Keywords: Cement Brick, Cellulose Fiber, Thermal Conductivity, Mechanical Properties, Physical Properties

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1. Introduction

The world is demand for sustainable construction industries and the demand is increasing in order to decrease the use of the construction materials and labour costs. The increasingly pressing environmental and climate emergency in which we live has influenced the agenda of various national and international organizations since the beginning of the twenty-first century, placing the challenge of creating a more sustainable society at the center of all development strategies [1]. At the moment, the demand for a more sustainable way of building seems to be no longer a matter of personal preference, and the sector has been regulated with the goal of implementing measures that improve the environmental behavior of infrastructures and buildings. The Department of Economic and Social Affairs from the United Nations has a new agenda for the sustainable development that will transforming the world in 2030. Through the establishment of the Sustainable Development Goals (SDGs), the development of a strategic plan to address the environmental, economic, and political challenges began. Sustainability is a main agenda in the United Nations' 17 sustainable development goals (SDGs) [2]. The use of sustainable materials in the construction industries are related to the agenda of the sustainable development goals (SDGs), which it is related to SDG 9 which is building resilient infrastructure, promoting inclusive and sustainable industrialization, and foster innovation and SDG 11 which is make cities and human settlements inclusive, safe, resilient, and sustainable [11]. The buildings, once constructed it will continue to be a direct source of pollution due to the emissions produced in them or their impact on the ground. The construction industry alone responsible for roughly 33% of global greenhouse gas emissions. The greenhouse effect from the building sector will increase further in the near future as energy consumption rises[3]. The expansion of Malaysia's industrial sector has resulted in numerous studies to reduce environmental pollution. To comply with the sustainable development goals (SDGs), the adding of natural material such as cellulose fiber in the production of cement bricks can reduce the environmental impacts from the construction sectors. It also can give and advantages to the production of the cement bricks as there is a lot of good things by using the cellulose fibres. Cellulose could be used for making air-to-air heat and mass exchangers to recover energy from outgoing air. Cellulose -based composite materials, such as wood, are renewable and biodegradable native polymeric composites composed primarily of cellulose, hemicellulose, and lignin, and are widely used in a variety of applications due to numerous advantages over other materials such as metal, cement, and synthetic polymers. Furthermore, the aesthetic qualities and low processing cost of these composites make them the most ideal materials for construction. Green building techniques are widely acknowledged to provide superior indoor environments that improve wellbeing, prosperity, and efficiency [4]. When used accurately, these techniques result in much more convenient and beneficial working conditions.[5].

1.1 Problem Statement

Cement is one of the contributors to the emission of the CO2 gases. The buildings, once constructed it will continue to be a direct source of pollution due to the emissions produced in them or their impact on the ground. The use of the cement bricks as a wall of the building can make the temperature of the building increases. common brick that being using in the construction industry nowadays are poor in thermal insulation. This can cause a building that using this common brick will absorb more heat when the weather is hot. The problem that is being faced by the industry is common cement bricks absorb heat more and this can make a building warmer than usual. It is not suitable for our country climate which mostly with high temperatures throughout the year. The global warming and increase in temperature especially in Malaysia are one of the effects from the polluted air because of the emission of the CO2 in the atmosphere which can thinning the ozone layer of the earth. This can lead to the greenhouse effect which can increase the temperature outside and inside of the building. The global warming also can lead to the long terms drought and also can melted the ice at the north which can lead to flood. This is because the demand of the construction materials especially cement. With the sustainable developments goals agenda (SDGs), the development of a strategic plan to address the environmental, economic, and political challenges began. To comply with the sustainable development goals (SDGs), the use of the cellulose fiber as an added material in the cement bricks can solve the problem of the common bricks. Cellulose fiber is a plant-based material that can be obtained from the bark, word or leaves of plants. By using the cellulose fiber, the expected result for the brick is to become heat resistant. Natural insulation materials, such as cellulose fiber, have a low environmental impact, a low embodied energy, and insulation properties comparable to synthetic materials[3]. Cellulose fiber is made from natural biomaterials. To mitigate the environmental effects of non-biobased materials, biobased materials are a natural alternative. Because the carbon emitted at the end of life is considered equal to the carbon sequestration at the forest, biobased materials are carbon neutral. The use of more natural biobased materials in buildings, such as cellulose fiber, can reduce the life cycle cost.

2. Test Conducting

All the works and the testing for this study were conducted at several lab such as Concrete Laboratory and Building Services Laboratory at Universiti Tun Hussein Onn Malaysia, Johor. There are 60 totals of sample with different proportion of material that were made for this study.

2.1 Materials and Mix Design Preparation

The materials that being used in this study are cellulose fiber powder made from bamboo plant with size of 300 microns, ordinary Portland cement, sand and water. All of this material will be mix together by following suitable proportion and step to achieve the result. The bamboo plants were obtained and collected at Parit Raja, Batu Pahat, Johor. Then, the bamboo will be extracted by using crushing method to become fiber and then the fiber is crushed by using planetary ball mill machine to become cellulose fiber powder. The size sample of the bricks is according to common size of brick in construction industry which is 215 mm in length, 102.5 mm height and 65 mm width and were prepared by different type of proportion of cellulose fiber powder to evaluate the properties and thermal performance of cement bricks compare with conventional cement bricks. The percentage of cellulose fiber powder that were used in this study are 5%, 10%, 15% and 20%. The mix design of the mixture was calculated with different type of proportion of cellulose fiber powder and the mixture was manually being mixed with calculated proportion in the mix design with 0.6 of water cement ratio used.

Table 1: Mix Design of the mixture

Samples	Percentage of Cellulose Fibre (%)	Cellulose Fibre Powder (kg)	Cement (kg)	Sand (kg)	Water (kg)
Control	-	0	7.29	29.04	4.8
CF 5%	5	0.039	7.29	29.04	4.8
CF 10%	10	0.078	7.29	29.04	4.8
CF 15%	15	0.117	7.29	29.04	4.8
CF 20%	20	0.156	7.29	29.04	4.8

2.2 Preparation of Sample Specimens

The moulds for the mixture are made of plywood according to the size of the sample. The mixture was manually being mixed by hand in the tray. After that, the mixture was poured into the moulds and being manually compacted by using tamping rod. After it reached 24 hours, the sample were demoulded and being place into curing tank until it reached the age of 7 days and 28 days of curing.

3. Laboratory Test

The sample of the specimens were undergoing 7 days and 28 days age of curing in the water tank before it was taken to undergo density, water absorption, ultrasonic pulse velocity, compressive strength and thermal conductivity test.

3.1 Density Test

The sample of the bricks is being weighed to record the mass of the samples. The value of the density of the sample is then calculated by using formula below.

$$\textbf{Density}, \boldsymbol{\rho} = \frac{\boldsymbol{m}}{\boldsymbol{v}} \qquad Eq.1$$

3.2 Water Absorption Test

Water absorption tests can be used to determine the degree of compactness of the bricks because the pores in the bricks will absorb water. Water absorption by bricks increases as the number of pores increases. The result recorded are computed by using the formula below.

$$\text{Percentage of water absorption} = \frac{wet\ mass\ (kg) - dry\ mass\ (kg)}{dry\ mass\ (kg)}\ x\ 100 \qquad Eq.2$$

3.3 Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity test is a non-destructive popular test for examining concrete homogeneity, quality, cracks, cavities, and defects. The velocity of the pulse is then measured by using the formula below.

$$\text{Pulse Velocity} = \frac{Width\ of\ sample}{Time\ taken\ by\ pulse\ to\ go\ through} \qquad Eq.3$$

Figure 2: Example of presenting data using a figure

3.4 Compressive Strength Test

The compressive strength test is carried out is to determines the maximum compressive load a material can withstand before fracturing. A gradually applied load compresses the test sample. There are few factors that influence the result of the compressive strength test, including the water-cement ratio, cement strength, quality of concrete, and quality control during the manufacturing process of the sample. Below is the equation for calculation the compressive strength of the sample.

$$\text{Compresive strength} = \frac{P}{A} \qquad Eq.4$$

Figure 3: Example of presenting data using a figure

3.5 Thermal Conductivity Test

Thermal conductivity testing measures a material's ability to transmit heat in watts per meter-kelvin of surface area for a temperature difference of K per unit thickness of 1m. It is represented by k, λ, or κ. Heat transfer is slower in materials with low thermal conductivity and faster in materials with high thermal conductivity.

4. Results and Discussion

The results and discussion section presents data and analysis of the study. This section can be organized based on the stated objectives, the chronological timeline, different case groupings, different experimental configurations, or any logical order as deemed appropriate.

Table 2: Result of sample specimen at the age of 7 days of curing

Samples	Density (kg/m3)	Water Absorption (%)	UPV at P1, P2 (km/s)	Compressive Strength (kN/m^2)	Thermal Conductivity (W/m^oC)
Control	2361.90	3.105	3.2, 3.1	32.94	0.195
CF 5%	2350.00	3.181	3.0, 3.2	35.46	0.178
CF 10%	2335.71	2.614	3.1, 3.0	33.50	0.153
CF 15%	2395.24	2.906	3.2, 3.1	33.18	0.175
CF 20%	2361.90	3.052	3.4, 3.9	36.53	0.162

Table 3: Result of sample specimen at the age of 28 days of curing

Samples	Density (kg/m3)	Water Absorption (%)	UPV (km/s)	Compressive Strength (kN/m^2)	Thermal Conductivity (W/m^oC)
Control	2359.52	3.204	3.2, 3.2	29.88	0.181
CF 5%	2383.33	3.046	3.1, 3.1	34.80	0.188
CF 10%	2345.24	2.986	3.2, 3.2	31.63	0.161
CF 15%	2390.48	3.032	3.3, 3.2	41.04	0.165
CF 20%	2435.71	3.134	3.4, 3.3	43.44	0.179

4.1 Density Test

The figure 4 below shows the results of density comparison between 7 days and 28 days of curing of the brick. For the control specimen, the graph shows that there is a slightly drop in results of density where specimen at 7 days is slightly higher than the specimen at 28 days of curing. The sample specimens of 5% and 10% shows a drop in density for the curing of 7 days where the density of the sample is lower compared to the control sample specimens. The sample specimens for control to 10% shows that the graph is start to fluctuated for the 28 days of curing. However, for the sample specimens of 10% to 20% it shows that the number of density is increasing for both 7 days and 28 days of curing. Besides that, the specimen sample of 10% has the lowest density among others for both 7 days and 28 days of curing. From the result, it can be absorbed that all of the density of the specimens has obtained has achieved the minimum requirements for density of normal weight which is more than 2000 kg/m^3 [6]. From the result data above, it shows that there is a different in the value of the density for all specimens for 7 days and 28 days of curing. This is because the presence of the cellulose fibre is different and variations in the percentage in every sample specimen so the void content of the bricks is also different.

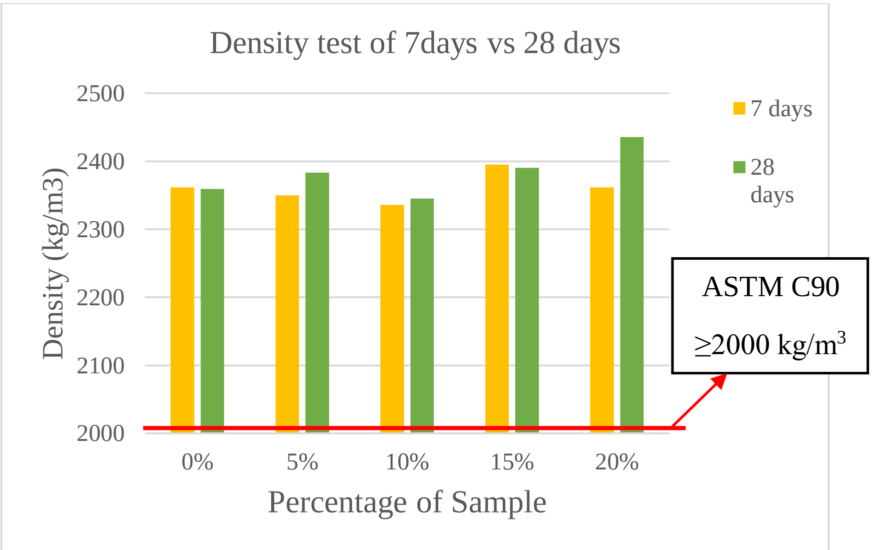

Figure 4: Graph of density versus the percentage of sample

4.2 Water Absorption Test

The sample of the bricks is being weighed to record the mass of the samples. Figure 5 below shows the plotted graph of water absorption versus the percentage of the sample. The water absorption for 10% of sample specimens shows the lowest rate of water absorption for both 7 days and 28 days of curing. While from 0% to 5% of the sample specimens the rate of water absorption is increase and start to fluctuated at 10% for 7 days of curing. The sample specimens for 0% to 20% shows that the graph start to fluctuated for the 28 days of curing. From the result obtained, it can be observed that all the water absorption of the specimen obtained has meet the standard requirement which is lower than 18% of water absorption [7]. Both sample of specimens at 7 days and 28 days has slightly different in the rate of water absorption obtained except for the 10% specimen at 7 days which has more different in the rate of water absorption than other percentage. Although an inconsistent data results of water absorption were obtained. It can be concluded that as the content of the cellulose fibre powder increased in the cement bricks, the more the water is being absorbed into the bricks so the more the rate of water absorption obtained. This is because there were different proportion of sample specimens in this study.

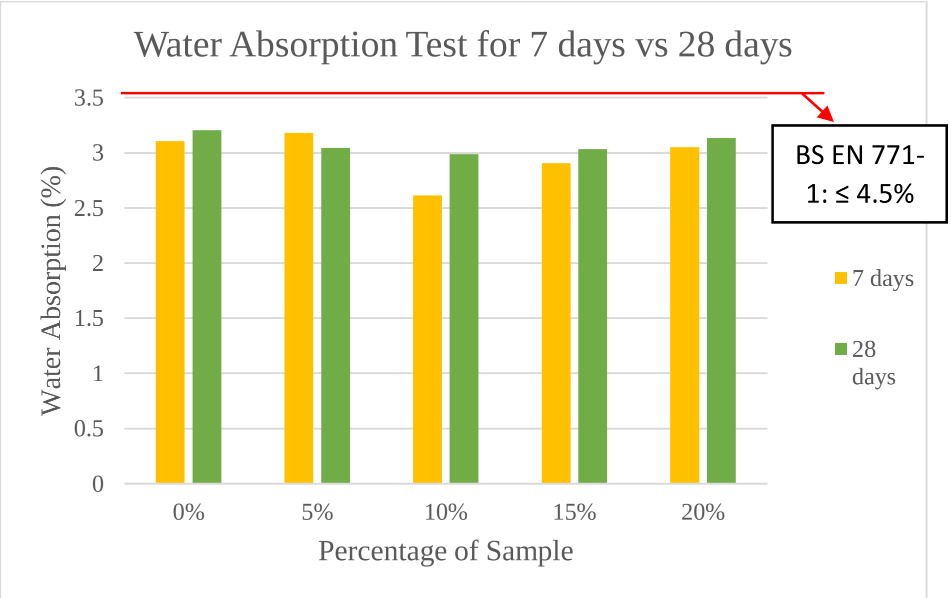

Figure 5: Graph of water absorption versus the percentage of sample

4.3 Ultrasonic Pulse Velocity Test

Figure 6 below is plotted based on the data obtained on the table. It can be absorbed that the value of pulse velocity from the specimen 0% to 10% is decreasing but the value increasing at specimen 15% to 20% for the age of 7 days. Meanwhile, the value of pulse velocity from the specimen 0% to 10% is start to fluctuated but the value then was increasing at 15% and 20% for the 28 days of curing. The average velocity value for the specimens 5% is constant at both 7 days and 28 days which is 3.1 km/s. It can be absorbed that the maximum value of the velocity obtained in this study is at 20% which is 3.6 km/s. The UPV test value in this study is increase with the increases of curing time. The smooth surface of the bricks is required to achieve the accurate velocity value of UPV. Table 4 below shows the classification of concrete quality ratings based on UPV test. From the result, it can be observed that most quality rating of specimens is at good (G) and medium (M). Based on this study, the range rating of the specimens achieve is in the range of 3.0 km/s to 3.6 km/s and it was classified as medium and good quality and meet the standard requirement.

Table 4: Classification of concrete quality ratings based on UPV test BS: 1881: Part 203 [8]

Pulse Velocity (km/s)	Quality (Ratings)
≥ 4.5	Excellent (E)
3.5 – 4.5	3.1, 3.1 (G)
3.0 – 3.5	3.2, 3.2 (M)
2.0 – 3.0	3.3, 3.2 (D)
≤ 2.0	3.4, 3.3 (VW)

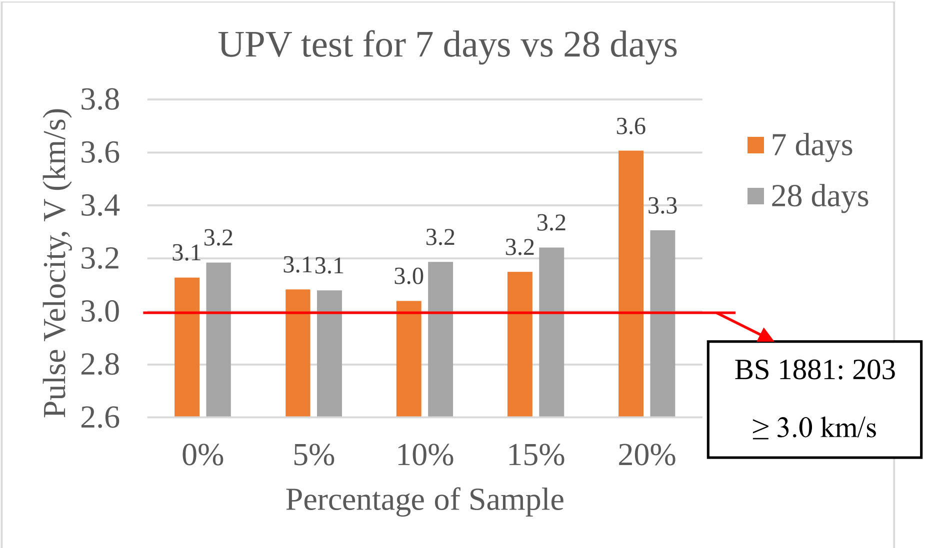

Figure 6: Graph of UPV versus the percentage of sample

4.4 Compressive Strength Test

Based on the figure 7 below, the graph shows that the compressive strength values of brick obtained by the specimen of 20% is the highest among other specimens in both age of 7 days and 28 days of curing. The value of compressive strength for specimens 15% and 20% is increase with increasing in the age of the samples and the percentage of cellulose fibres of the sample. The value of compressive strength from the specimen 0% to 10% is fluctuated but the value then was increasing at 15% to 20% at the age of 7 days of curing. Meanwhile the value of compressive strength from the specimen 0% to 10% is also fluctuated but the value then was increasing at 15% to 20% at the age of 28 days of curing. It can be absorbed that, all of the specimens that contains cellulose fibre powder in the bricks obtained higher number of values of compressive strength than the 0% of specimens. This shows that the cellulose fibre powder use in the mixture influence the strength of the bricks. From the result data, the compressive strength obtained for the specimens has meet the requirement and the value is higher than the standard requirements of compressive strength which is 3.5 N/mm^2 [9].

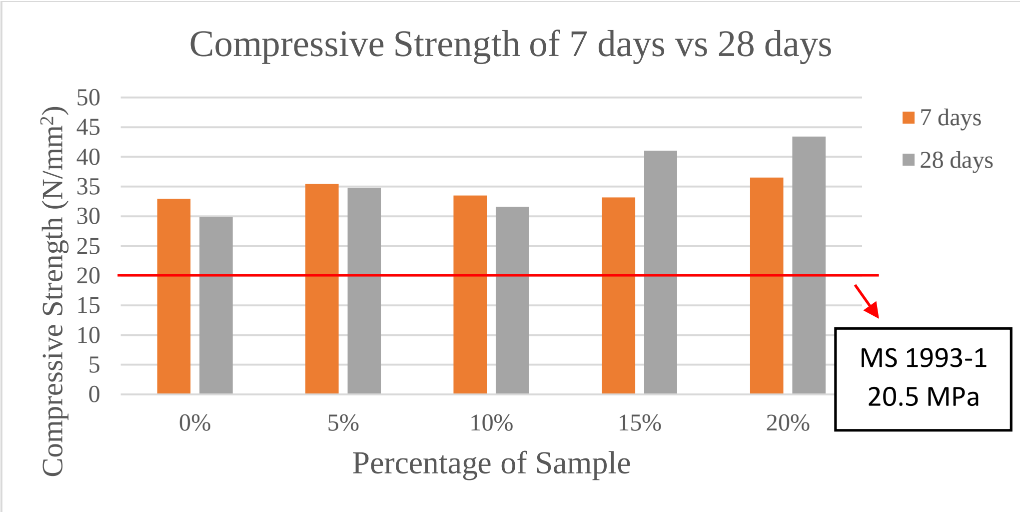

Figure 7: Graph of compressive strength versus the percentage of sample

4.5 Thermal Conductivity Test

Based on the figure 8 below, it can be observed that the sample specimens for 0% obtained the highest value of thermal conductivity which is 0.195 W/m°C for the age of 7 days of curing. Other than that, the sample specimens for 5% obtained the highest value of thermal conductivity which is 0.188 W/m°C for 28 days slightly lower than the highest value of specimens of 7 days. Figure 8 above shows the graph that was plotted based on the result obtained on table 4.10 above. From the graph, it can be absorbed that the value of thermal conductivity is decreasing starting from the specimen's sample 0% to 10% but the value of thermal conductivity then increases from specimens sample 15% and 20% for the age of 7 days of curing. Besides, the value of thermal conductivity is start to fluctuated starting from the specimens sample 0% to 10% but the value of thermal conductivity then increases from specimens sample 15% to 20% for the age of 28 days of curing. Based on the table and graph plotted below, it can be absorbed that the specimen's sample of 10% obtained the lowest value of thermal conductivity which is 0.153 W/m°C for the age of 7 days and 0.161 W/m°C for the age of 28 days. All specimen samples that contains cellulose fibre powder obtained lower value of thermal conductivity than the specimens sample of 0% at both 7 days and 28 days of curing.

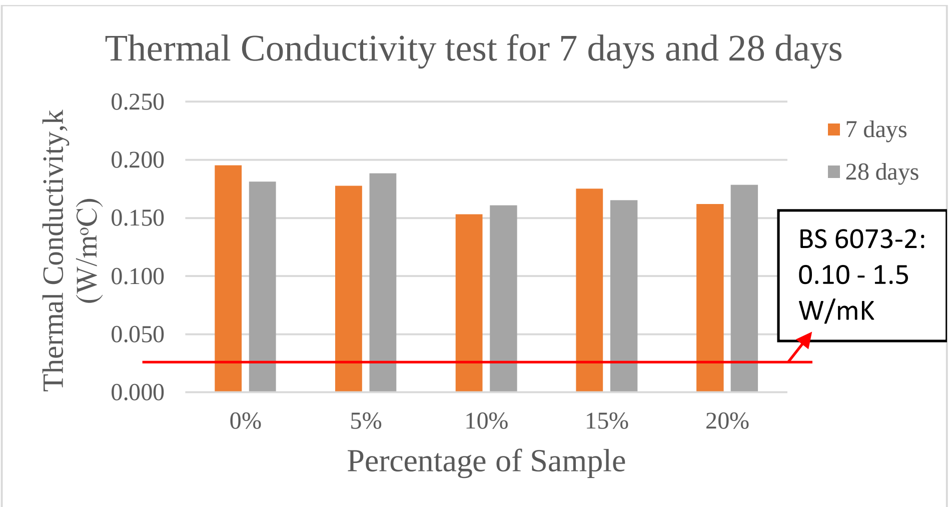

Figure 8: Graph of thermal conductivity versus the percentage of sample

5. Conclusion

In conclusion, the compressive strength obtained by the specimen sample of 20% is highest among the other sample with 36.53 kN/m2 and 43.44 kN/m2 for both 7 days and 28 days of curing due to the higher contain of cellulose fiber powder in the specimens so greater bonding is influence the result of compressive strength for both 7 days and 28 days of curing. To calculated the load-bearing capacity of the bricks, the compressive strength is the most important factors that should be consider in producing the construction materials to withstand pressure. Furthermore, the value of the velocity obtained by the sample of 20% is also the highest among others sample with 3.6 km/s and 3.3 km/s respectively on both 7 days and 28 days of curing. The UPV test value in this study is increase with the increases of curing time by using the direct transmission methods. The smooth surface of the bricks is required to achieve the accurate velocity value of UPV. This study obtained the optimum rating of velocity which in the range 3.0 km/s to 3.6 km/s and it was classified as medium and good quality of construction materials. The value of the thermal conductivity of the bricks for the specimens sample of 10% obtained the lower value of thermal conductivity with 0.153 W/m^{o}C for the age of 7 days of curing and 0.161 W/m^{o}C for the age of 28 days of curing due to the density of the sample. The results show that all the sample bricks that containing cellulose fiber powder have the lower thermal conductivity than the sample of 0%. From the result that has obtained, the value of thermal conductivity of all specimens has meet the standard requirements for thermal conductivity which is 0.69 W/ m^{o}C and below [10].

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