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Research article

Utilization of fly ash cenosphere to study mechanical and thermal properties of lightweight concrete

Salmia Beddu, Mushtaq Ahmad*, Daud Mohamad, Muhamed Imran bin Noorul Ameen, Zarina Itam, Nur Liyana Mohd Kamal, and Nur Amalina Nadiah Basri

Department of Civil Engineering, Universiti Tenaga, Nasional Putrajaya Campus, Malaysia

* **Correspondence:** Email: ma_5099@yahoo.com.

Abstract: The utilization of cenosphere by-product of fly ash as a substitution of sand in concrete is an effective way to reduce thermal conductivity. This study investigates the mechanical and thermal properties of cenosphere substituted in the lightweight concrete. Cenosphere is the recycled material and possesses good thermal insulation properties. Study objectified replacement of sand over the FA cenospher to study the mechanical and thermal properties of the concrete. Experimental setup of the study 10%, 20% and 30% sand by weight is replaced with cenosphere. Concrete specimen prepares and cured for the period of 3, 7 and 28 d. Compressive strength of the concrete is analyzed for 3–7 and 28 d where tensile strength is analyzed for 28 d. Study shows significant improvement in the compressive strength and tensile strength. Thermal conductivity is analyzed for 28 d cured concrete samples using Heat flow FOX-50 instrument. Thermal conductivity reduces by 35% with the replacement of 30% sand over cenosphere which shows the significant reduction. Due to the lower density of cenosphere density of concrete samples reduced which is one of the leading factors to the lower thermal conductivity. Study concluded by replacement of 30% FA cenosphere compressive strength increased conversely thermal conductivity and density of the concrete specimen has reduced.

Keywords: fly ash cenosphere; compressive strength; tensile strength; thermal conductivity; density; lightweight concrete

1. Introduction

Concrete is the single most widely used material on earth after water [1–2]. Concrete is the mixture of naturally occurring aggregate of about 70–80% followed by fillers and binding materials such as cement [3]. To understand the urgency of the research, the extensive utilization of concrete itself is massively destructive to human health on the plant. Concrete is one of the leading cause factors for increasing carbon footprint on earth [4]. Growing concern over the utilization of waste materials may enhance the concrete properties by replacing with cement/filler or with coarse aggregate been trending from past decades [5]. Among the waste materials FA use has positive impact on the economic aspect as it reduces the cost of concrete production by reducing the content of expensive cement in its composition. FA use in concrete reduces industrial waste landfills followed by reduction of CO_2 and green gas emission from the cement production [6]. Cenosphere addition to the concrete is to reuse waste materials which have the inverse effect on the climate change. The high demand and utilization of natural materials may cause scarcity thus preparing alternative materials would be helpful. Numerous studies have been conducted to meet with the challenge of findings alternative materials. This study is mainly focusing on the energy part. Global leaders and United Nations organizations passionately looking onto the matter of climate change. United Nations general assembly meeting 2019 largely focused on the sustainable development and green buildings to enhance the people living life in contrast to combat climate change [7,8]. The one attempt to combat with climate change is the energy conversation. Globally, building infrastructure contribute about 30% greenhouse gas emissions [9–10]. Today building infrastructure plays multiple role and people are spending much of time indoor where energy conversations and thermal comfort is important.

Dynamically, thermal comfort and energy required for the cooling and heating of the building is highly depend on the thermo-physical properties of the construction materials used in the building [11]. Concrete is the key building material and extensively use up to 10 billion tons per year and expected to increase up to 18 billion tons in 2050 [12]. The high demand and on large scale utilization has created interest among researchers to investigate thermo-physical properties of the concrete. The main thermo physical properties of the materials are thermal conductivity, specific heat and thermal diffusivity. Thermal conductivity is important because it allow the heat transfer in the material or concrete. Low heat transfer and energy consumption has been observed in the buildings constructed with lower conductive materials [13]. Conventional concrete which is most widely used in the construction is poor insulating materials with high thermal mass. Conventional concrete store heat energy absorb due to high thermal conductivity and less insulation. Study [14] postulated that light weight concrete applied in the buildings of European countries may has reduce about 15% heating energy compared to buildings constructed with normal concrete. Study [15] has modified concrete by replacing cement with FA resulted potentially high environmental benefits such as reduction of energy use for cement production. Addition of 20–30% siliceous FA to the fresh concrete significantly reduce the fracture toughness of concrete while over 28 d of cured concrete with 20% slightly increase mode KIIIc fracture followed with 30% addition of FA reduced significantly fracture toughness [16].

Thus, it is essential to find alternative lightweight materials to enhance the thermal insulation properties of concrete to reduce heat energy in the building further leads to the energy saving buildings to cope climate change global issue.

2. Literature review

In the introduction part enlighten importance of concrete utilization in the civil engineering practice worldwide and future demand has discussed. Due to high demand and very friendly adoption nature of concrete today science engineering is focusing on the importance aspect of heat island largely generated by the concrete massive structure and impact on the climate change which cannot be ignored. Thus, the engineers and scientist are contributing to design concrete with less thermal conductivity by addition of waste materials is to cope with climate change challenge. In this review, the aim of this paper is to evaluate the techniques that can be used and also by considering the factors that affect the thermal conductivity (K-values). Thermal conductivity of concrete is seen as the important factor to monitor the heat transfer through conduction. Thermal conductivity decreases by utilization of insulating materials [13]. Generally, steady state and transient method is use to determine the thermal conductivity of the material technically both has different approach where in the steady state method temperature is constantly applied and not dependent on time. Steady state commonly chooses if the materials are homogenous.

Whereby transient method heat flow/temperature changes over time can say transient method is time dependent method. Transient method used for non-homogenous (heterogeneous) materials with moister content [13,17–18]. Study of [13] comprehensively analyzed the thermal conductivity of concrete and concluded transient method is commonly used to find the K values of concrete time, equipment availability and cost might be the reason but since concrete is not homogenous material and has always moisture content is most justified reason transient method used to find K values.

Thermal conductivity of concrete and governing factors concluded by [18] are types of aggregate materials, cement content, water content and air voids content additionally temperature and moister condition of the concrete. Moisture content and mineralogical characteristic of concrete are leading factors of high thermal conductivity [19]. Study of [20] added light weight material such as perlite in the concrete result shows significant reduction of thermal conductivity of concrete to 0.1472 w/mK. In the concrete higher is the cement content higher is the thermal conductivity addition of powder materials like FA, steel slag help to reduce the K value because reducing the cement content. Study shows significant reduction of thermal conductivity of concrete by addition of FA [21]. Study conducted by [22] found that addition of lightweight perlite aggregate help to reduce density, flexural strength and thermal conductivity at 70% addition is 6.3 times less than control/normal concrete. Research Study conducted by [23] has strongly recommended the low water/binder ratio for concrete mix. Moreover, high degree of homogeneity in the concrete mixes leading better performance small internal microcracks and greater resistance to dynamic loads. Expended polystyrene (EPS) was added into the concrete result indicated increasing volume of EPS significantly reduce the thermal conductivity of the concrete [24]. Natural aggregate was replaced with modified expended polystyrene (MEPS) findings indicated that increasing the replacement of natural aggregate with MEPS significantly reduce the thermal conductivity of the concrete [25]. Concreter incorporation with FA 30% to over 40% remarkably improves the strength properties of concrete. Cement replacement with FA in the concrete mix has significantly environmental benefits as well reduce the electricity consumed while cement productions [15]. Light weight concrete added 30% FA decreased water absorption, density, compressive strength and thermal conductivity of concrete [26]. Study claimed light foamed concrete (LFC) is highly thermal resistance compare to ordinary concrete and produce better energy efficacy for use as non-structural alternative materials in tropical climates [27]. Thermal insulation materials play an important role in reducing power requirements and greenhouse gas emissions. There are some factors mainly affecting the thermal conductivity of the concrete are types of aggregate materials, cement, fine aggregate, water cement ratio and moister content. Where it found that light weight concrete has the lower thermal conductivity compare to the normal concrete. Many attempts have been made in the past to reduce the thermal conductivity of concrete by adding and replacing main aggregate materials. In this study, by products of the fly ash known cenespher is suggested to use. Cenosphere by product of the fly ash can be separated from FA using sink float method. Cenosphere possess good mechanical properties such as high compressive strength and a good thermal insulator. Conventional cement can be used with cenosphere to produce a lightweight concrete.

3. Material and methods

3.1. Cement

Table 1 shows the ordinary Portland cement (OPC) chemical composition and physical properties and type-1 cement with density of 3150 g/cm^3 in accordance to ASTM C150 is used in this study.

Table 1. Physical and chemical property of OPC.

Chemical property	Percentage (%)	Physical property	Results
CaO	60.7	Size	≤75 μ
SiO_2	21.9	Fineness	91%
Al_2O_3	7.4	Normal consistency	26%
Fe_2O_3	5.7	Initial stetting time	33 min
MgO	4.5	Final stetting time	408 min
SO_3	3.9	Specific surface	322 m^2/kg
K_2O	2.4	Soundness	1.30%
Na_2O	0.2	28-days compressive strength	42 MPa

3.2. Fine and coarse aggregate

Natural sand was used as a FA (fine aggregate) in all the mixes in SSD (saturated surface dry) condition. Normal weight coarse aggregate (crush stone) in saturated dry condition (SSD), Nominal maximum size of coarse aggregate is 19.5 mm. Different tests were performed on aggregate to evaluate its physical property as shown in Table 2.

Table 2. Physical property of fine and coarse aggregate.

Physical property	Fine aggregate	Coarse aggregate
Particle size (mm)	4.75–0.075	19.5–4.75
Fineness modulus	2.83	4.3
Absorption capacity (%)	5.08	3.13
Moisture content (%)	2.8	1.25
Bulk density (kg/m^3)	1586	1565

Sand (Silica) is substituted by weight 10%, 20% and 30% with cenosphere. Polypropylene fiber 0.5% was added by weight to increase the workability of the concrete. Lightweight expended clay aggregate (LECA) 2–4 mm diameter with density of 448 kg/m^3 was used in this study. Compressive and tensile strength test and thermal conductivity test were conducted. All tests were carried out by following British (BS) and Malaysian JKR (Public Works Department) standards. Concrete specimens were prepared in the civil Engineering laboratory at Universiti Tenaga Nasional (Uniten) Engineering campus Malaysia. Workability of the concrete mixed is increased and maintained using superplasticer doze where polypropylene is added to increase the durability of the concrete. Table 3 shows the concrete mix design

Table 3. Concrete mix design for control samples and addition of cenosphere.

	Control sample (0%)	Cenesphere (10%)	Cenesphere (20%)	Cenosphere (30%)
Ingredients (kg)		3.06	6.12	9.18
Cement (kg)	15.80	15.80	15.80	15.80
Sand (kg)	30.60	27.54	24.48	21.42
LECA (kg)	25.4	25.4	25.4	25.4
Water	7.9	7.9	7.9	7.9
Polypropylene fiber	0.079	0.079	0.079	0.079

3.3. Compressive test

The test aim is to measure the performance of concrete. Concrete cube size of 0.1 m^3 was prepared and cured for 3, 7 and 28 d before tested using universal compressive testing machine.

3.4. Tensile strength of concrete

Concrete has the lower tensile strength compare to compressive strength. Tensile test was conducted and specimen prepared size of 0.075 × 0.030 m cylinder has prepared and cured for 28 d. Universal tensile machine is used to test the tensile straight of the concrete beam.

3.5. Thermal conductivity test

Thermal conductivity is a test to measure the rate and amount of heat that passes through the concrete specimen in a period of time. The set point temperature will be set to 0–60 ºC in order to produce different set of results to be analyzed. Heat Flow meter FOX-50 instrument is used to measure the heat flow/thermal conductivity of the concrete samples sample casted according to the specification and tested for an hour. Specimen preparation for the thermal conductivity analysis is shown in the Figures 1–3. The 28 d cured concrete samples is shown in Figure 1.

Figure 1. 28 d concrete samples.

Figure 2. Concrete samples is cored and sliced for Heat Flow test.

Figure 3. Selected slice samples for the Heat Flow test.

4. Results and discussion

4.1. Compressive strength of modified concrete

Concrete cube dimension of 0.1 m × 0.1 m × 0.1 m with curing periods of 3, 7 & 28 d were tested for the compressive strength (MPa) in compression by using ELE International Compression Machine. Table 4 indicated the compressive strength of 3 d curing period as shown. Each specimen test has repeated three time's findings shows addition of 20% cenosphere has the highest compressive strength of 23.9 MPa. Moreover, above 30% addition reduce the compressive strength of concrete.

Table 4. Compressive test results for 3 d.

No. of days	Mix design	Specimen No.	Strength (MPa)
3	Control	1	4.4
		2	5.0
		3	5.1
	10% CE	1	6.1
		2	7.4
		3	5.8
	20% CE	1	10.6
		2	16.9
		3	23.9
	30% CE	1	11.6
		2	14.2
		3	5.3

Cenosphere were added 10%, 20% and 30% with the partially replacement of sand. On the 7th days curing period specimen were tested for compressive test. Findings drafted in the Table 5 shows that 20% replacement has the highest compressive strength of concrete on the 7th days of curing period. Conversely more addition of cenosphere resulted lower compressive strength of concrete.

Table 5. 7 d compressive strength of concrete mix.

No. of days	Mix design	Specimen No.	Strength (MPa)
7	Control	1	8.7
		2	9.9
		3	10.6
	10% CE	1	14.6
		2	19.8
		3	18.3
	20% CE	1	20.4
		2	25.4
		3	18.2
	30% CE	1	11.7
		2	12.2
		3	14.3

Table 6. 28 d compressive strength of concrete mix.

No. of days	Mix design	Specimen No.	Strength (MPa)
28	Control	1	11.6
		2	14.2
		3	5.3
	10% CE	1	28.8
		2	27.3
		3	24.5
	20% CE	1	28.8
		2	25.5
		3	27.0
	30% CE	1	21.9
		2	17.7
		3	18.5

Modified concrete specimen was tested for compressive strength on 3rd, 7th and 28th days of curing. Table 6 shows 28th days' compressive strength result. In the comprassion result with 3rd day, 7th day and 28 d shows that compressive strength of concrete increased by addition of cenosphere 20%. More than 20% addition such as 30% addition shows lower compressive strength for 3rd day, 7th day and 28 d likewise. Study has observed that cenosphere addition up to 20% in the concrete increase the compressive strength of concrete in the range of 25–30 MPa. Highest compressive strength that has observed on 28th days is 28.8 MPa. Addition of cenesphere by 20% significantly improved the compressive strength for 3–7 and 28 d where more addition or replacement with sand shows lower compressive strength. For concrete curing day 7 with 10% CE, 30% increase of strength is achieved whereas for 20% CE, 35% increase in strength is achieved. 28 d of concrete curing is known as the day concrete reaches highest strength. Highest strength is achieved in the project with an increase of strength of 40% in 10% CE and 43% in 20% CE. Overall study found that addition of cenesphere in concrete increased the compressive strength by 43% in the curing period of 28 d.

4.2. Test result for split tensile test

Split Tensile is done to observe the tensile strength of the concrete which is by splitting the cylinder at the center of the concrete. Concrete with 28 d of curing is used to obtain the highest tensile strength. The machine used for this test is Universal Testing Machine (UTM). The cylinder is placed in horizontal and two bearing plates are placed in between of the cylindrical concrete and the loads are applied gradually. The max load applied on the samples is used to calculate splitting strength. Figures 4 to 7 as shown below indicated the result of tensile strength.

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43003 Kajang, Selangor

Test Report (Compression)

Test Date:12-09-2019

Test Time: 11:01:00

Sample	Weight g	Length mm	Height mm	Width mm	Area mm²	Elastic modulus MPa	Stress N/mm²	Max. Load kN
S1 0% 28D	1000	300	150	75	4418	2120.82	16.05	70.90
S2 0% 28D	1000	300	150	75	4418	1977.75	20.39	90.10
S3 0% 28D	1000	300	150	75	4418	1722.01	17.88	79.00

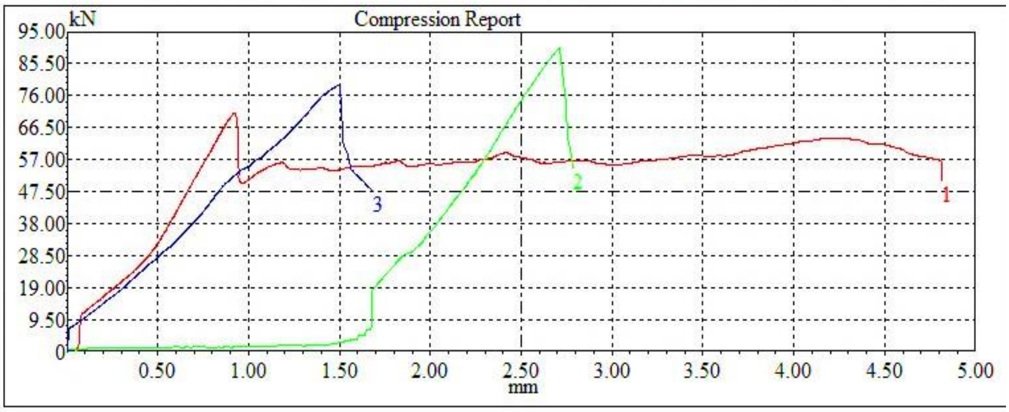

Figure 4. Split tensile result for control sample.

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Test Report (Compression)

Test Date:12-09-2019

Test Time: 11:06:14

Sample	Weight g	Length mm	Height mm	Width mm	Area mm²	Elastic modulus MPa	Stress N/mm²	Max. Load kN
S1 10% 28D	1000	300	150	75	4418	4309.39	37.15	164.13
S2 10% 28D	1000	300	150	75	4418	4701.46	35.00	154.61
S3 10% 28D	1000	300	150	75	4418	8290.73	32.54	143.76

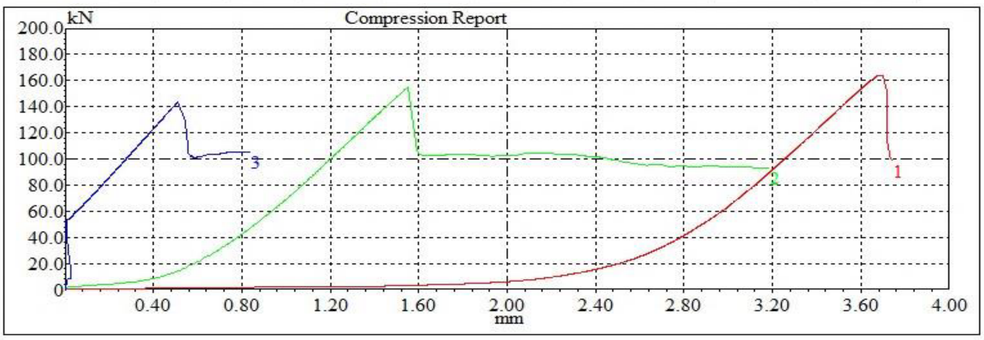
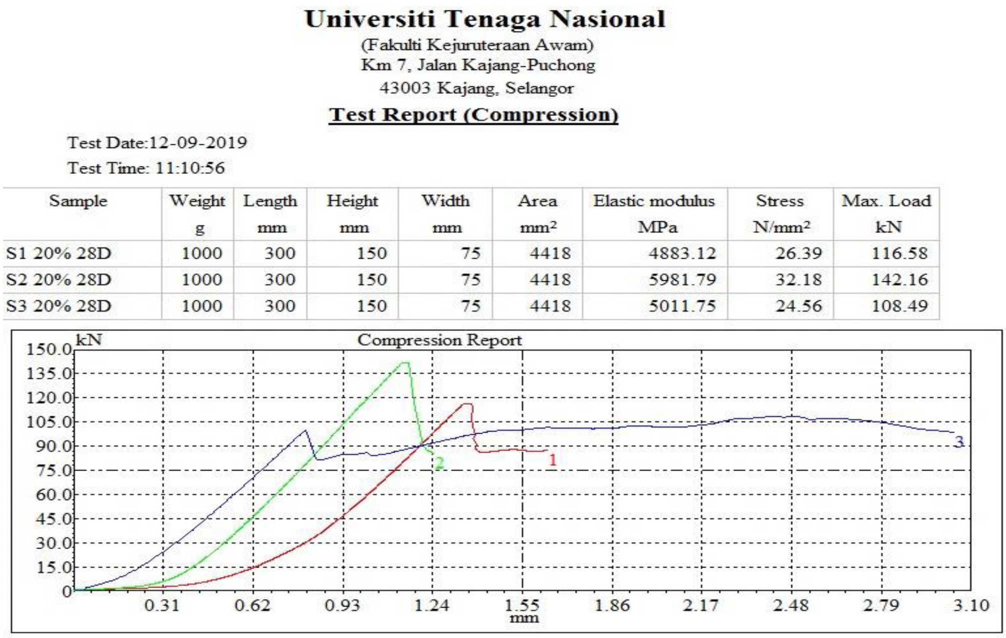


Figure 5. Split tensile result design 10% CE.



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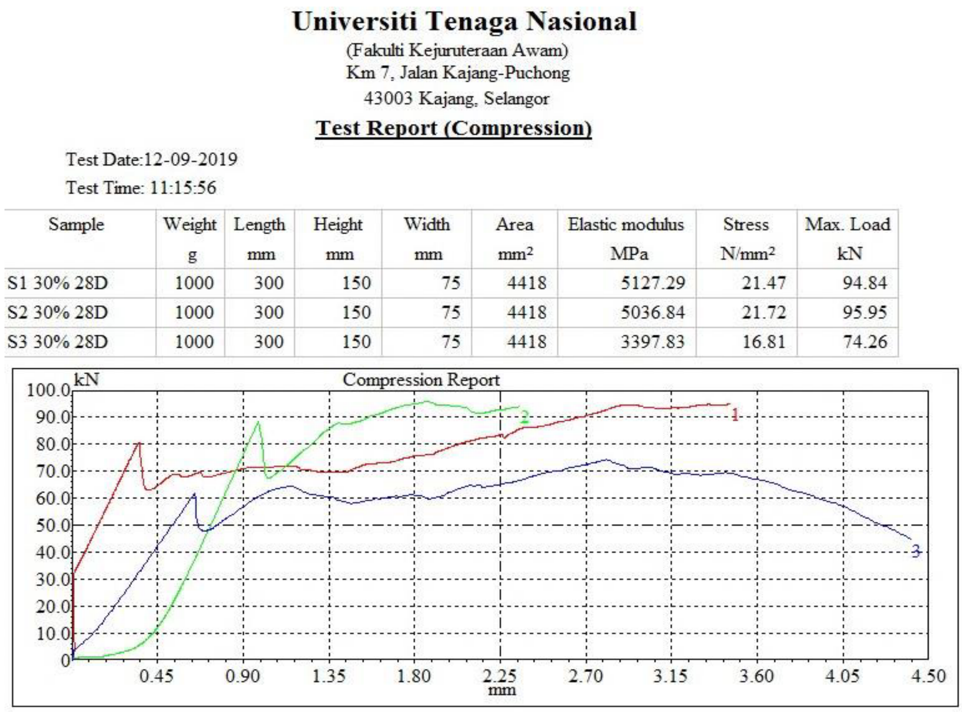
Test Date:12-09-2019
Test Time: 11:10:56

Sample	Weight g	Length mm	Height mm	Width mm	Area mm²	Elastic modulus MPa	Stress N/mm²	Max. Load kN
S1 20% 28D	1000	300	150	75	4418	4883.12	26.39	116.58
S2 20% 28D	1000	300	150	75	4418	5981.79	32.18	142.16
S3 20% 28D	1000	300	150	75	4418	5011.75	24.56	108.49

Figure 6. Split tensile result design 20% CE.



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Test Report (Compression)

Test Date:12-09-2019
Test Time: 11:15:56

Sample	Weight g	Length mm	Height mm	Width mm	Area mm²	Elastic modulus MPa	Stress N/mm²	Max. Load kN
S1 30% 28D	1000	300	150	75	4418	5127.29	21.47	94.84
S2 30% 28D	1000	300	150	75	4418	5036.84	21.72	95.95
S3 30% 28D	1000	300	150	75	4418	3397.83	16.81	74.26

Figure 7. Tensile result design 30% CE.

Each Specimen is tested three times and average result is signified in Table 7. The average tensile strength result for the control mix is 1.131 MPa. Addition of 10% cenesphere result shows the maximum tensile strength of 2.180 MPa. Further addition of cenesphere of 20% and 30% average results shows 1.732 MPa and 1.250 MPa. The tensile strength can be seen to be increasing by addition of 10% when sand is replaced by 10% of cenesphere. This is to show that CE addition to the mix should be kept at 10% for it to work as a resistance to tensile forces. From the results, it shows that once sand is replaced by 20–30% of CE, reduction in tensile strength will happen. Highest tensile strength obtained is 2.321 MPa in design.

Table 7. Tensile/splitting strength of concrete.

Mix design	Sample No.	Splitting strength (MPa)	Average strength (MPa)
0% CE	1	1.003	1.131
	2	1.274	
	3	1.117	
10% CE	1	2.321	2.180
	2	2.187	
	3	2.033	
20% CE	1	1.649	1.732
	2	2.011	
	3	1.535	
30% CE	1	1.341	1.250
	2	1.357	
	3	1.051	

4.3. Thermal conductivity analysis

Thermal conductivity test is conducted using FOX 50 heat flow meter (instrument). Heat flow instrument draft the result of concrete specimen thermal conductivity, density and weight loss of the concrete sample during the process of heat flow before and after as measured. Correction factor is applied for thermal conductivity (W/mK) values because of the rubbers used in between of the samples when conducting the test in FOX 50. Two samples from each concrete mix design of 28 curing days are taken for the test. All samples were kept in the oven for 24 h to ensure moisture content completely dry. Temperature is set at 28 ºC (Malaysia temperature). Table 8 shows the thermal conductivity of concrete samples.

Table 8. Thermal conductivity and density.

Design mix	Average TC (W/mK)	Average density (kg/m^3)
Control sample	1.2873	1896.5
10% cenosphere	1.0795	1895.0
20% cenosphere	0.9463	1827
30% cenosphere	0.8445	1592.9

Thermal conductivity results obtained for two samples from each mix design are tabulated in Table 6. Thermal conductivity of the concrete values according to the literature shows in the range 1.0–2.5 W/mK. The result shown in the Table 6 indicated that control sample has the highest thermal conductivity of an average 1.2873 W/mK.

Density of the lightweight concrete is 1840 kg/m^3. Replacement of sand 10% over cenosphere shows almost 13% reduction of thermal conductivity average values 0.9988 W/mK. Replacement of cenosphere by 20% reduces average thermal conductivity 0.9463 W/mK which is about 27% reduction in the thermal conductivity. Findings shown in the Table 6 indicated that replacement of cenosphere with sand by 30% reduce thermal conductivity of 0.8445 W/mK which is about 35%. Water cement ratio plays an important role and strict control has been taken care for every mix.

Study of [28] found that FA incorporation with concrete effectively reduce thermal conductivity and density of the concrete. Coarse aggregates selection can play vital role in further reducing the thermal conductivity values. This can be seen in the review paper by [13] has stated the factors affecting thermal conductivity are humidity, temperature, type of aggregate and cementing materials. Inhomogeneity and the geometry of the materials affect the thermal conductivity of the concrete mix [29]. In addition, partial evaporation of the mix design water content decreases the thermal conductivity. Cenosphere has less density compare to the water findings shown in the Table 6 indicated that density of the concrete samples decrease as the replacement of the cenosphere over sand increased. Thermal conductivity has direct relation with the density of the concrete. Thermal conductivity increased as the density increased but study witnessed replacement of sand with FA cenosphere decreased the density and positively decrease the thermal conductivity of the concrete. Higher density concrete has the higher thermal conductivity and thermal conductivity of concrete varies with the density of concrete [30]. The mineralogical character of the aggregate greatly affects the conductivity of concrete.

5. Conclusion

Study has follow conclusions:

(1) Partial replacement of sand with cenosphere significantly increases the compressive strength of the lightweight concrete.

(2) Addition of cenosphere by 20% has significantly improved the compressive strength for 3–7 and 28 d where more addition or replacement with sand shows lower compressive strength.

(3) Compressive strength increased 40% and 43% by addition of 10% and 20% cenosphere respectively. Highest compressive strength that can be produced by the concrete is 28.8 MPa which is good for a lightweight concrete.

(4) Study concluded that tensile strength of concrete improved by replacement 10% of sand over FA cenosphere. Further addition of cenosphere shows lower tensile strength compare to 10% addition. It can conclude if desired high tensile strength in the concrete the replacement ratio keep 10% but if purpose is to achieve high compressive strength 30% addition shows the highest compressive strength of the concrete.

(5) To analyze and reduce thermal conductivity of the lightweight concrete is the main focus of this study. Study concluded that replacement of the sand with fly ash cenosphere reduces the thermal conductivity and the density of the lightweight concrete as the finding is shown in Table 5.

(6) Replacement sand over FA by 30% significantly reduces the thermal conductivity about 35%. The thermal conductivity of the control mix concrete is 1.28 W/mK where addition of 10% to 30% the thermal conductivity is reduce respectively 0.9988 W/mK, 0.9463 W/mK and 0.8445 W/mK which marked about 35% thermal conductivity has reduced.

(7) Findings indicated that cenosphere reduce the density of concrete which is the leading factor to reduce the thermal conductivity of the concrete.

(8) Study found the density of concrete has direct relation with thermal conductivity.

(9) Replacement of sand over cenosphere significantly reduces the density and thermal conductivity of the concrete.
(10) Thermal comfort in the concrete structures and copping with the climate change can be significantly reduced by the utilization of cenosphere in the concrete to replace sand. Fly ash cenosphere can be recommended to utilize in the construction projects where desired compressive strength is required this will help to reduce thermal conductivity of the concrete structures.

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Conflicts of interests

The authors have no conflict of interest to declare.

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