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Investigation of Thermal Properties of Normal Weight Concrete for Different Strength Classes

Hamed Rezaei Talebi [1], Brit Anak Kayan [2*], Iman Asadi [3], Zahiruddin Fitri Bin Abu Hassan [4]

[1]Department of Building Surveying, Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]Center for Building, Construction & Tropical Architecture (BuCTA), Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia

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Abstract

Concrete is a common construction material which its thermal properties influence on energy consumption of buildings, significantly. The main aim of this study is to investigate the thermal properties of normal weight concrete for different strength classes and the performance of normal weight concrete was measurement by studying the mechanical, physical and thermal properties. Also, develop the correlations between thermal properties with mechanical and physical properties. The results showed that the thermal properties of concrete would be changed based on its different strength classes. The results indicated that the thermal conductivity, specific heat capacity and thermal diffusivity of normal weight concrete with a compressive strength in the range of 15 to 62 MPa are in the range of 1.6 to 3.2 W/m.K, 0.92 to 1.16 kJ/kg.K and 0.69 to 1.34 ($\times 10^{-6}$ m^2 /s), respectively.

Keywords: Normal weight concrete, Thermal conductivity, Thermal diffusivity, Specific heat capacity

1 Introduction

Concrete is a widely used construction material of the world, that annual production of 5.0 billion cubic yards, the concrete used amount is almost double of all other construction industrial materials, the main detail mix proportions of concrete with the water-cement ratio an important factor that effect on the strength of concrete [1].The buildings are responsible for a third of the total energy consumption and emit 30% of greenhouse gases (GHGs) in the atmosphere [2]. The energy needed for heating and cooling of structure also thermal tranquility almost depend on the thermal properties of the materials used in constructing a building [3]. The thermo-physical properties of construction material play a significant role in achieving the energy required for heating and cooling.

Compared to other building materials such as wood, steel, and plastic, concrete is used twice as much in the construction of buildings [4]. More than 10 billion tons of concrete is produced each year [5] and it is expected that it reaches 18 billion tones by 2050 as demand for concrete continues to rise [6].

The thermal conductivity (k-value), specific heat capacity (c-value) and thermal diffusivity (α) represent the thermo-physical properties of a material, the key thermal property affecting the transfer of heat by conduction through concrete is thermal conductivity, Asadi et al. reported that the thermal conductivity for different types of concrete was 2.24 to 3.85 (W/m.K) [7]. Conduction heat transfer in concrete occurs through vibrations of the molecules and energy transport by free electrons [8]. Thermal diffusivity indicates the speed of heat transfer through concrete in transient heat transfer conditions.

Concrete is a mix of cement, water, coarse aggregate, fine aggregate and admixture in some cases. Changing in each component will be changed the thermal properties of concrete, around 60% of the concrete volume consists of aggregate [9]. According to available literature, the thermal conductivity of aggregate used in concrete is in the range of 1.163 to 8.6 W/m.K [10]. However, the thermal conductivity of concrete has been reported in the range of 0.2 to 3.3 W/m.K [11, 12, 13, 14].

Using lightweight aggregates as a replacement normal weight aggregates of concrete reduce the thermal conductivity significantly.Replacement the fly ash can reduce the thermal conductivity of concrete up to 80% [15]. In another study, Huang et al. revealed that the thermal conductivity of concrete with replacement fly ash is around 21% than a normal one [16]. A study reported the k-value of concrete is around 0.22 W/m.K while tobacco waste added to mix [17]. Howlader et al. reported that specific heat capacity of concrete containing burnt clay brick-chips as aggregate is 13% greater than the concrete having stone-chips, furthermore, the achieved results show that the thermal diffusivity of concrete with burnt clay brick-chips was 19% lower than stone-chips concrete [18].

Utilizing cementitious material as cement replacement can change the thermal properties of concrete. Wongkeo et al. reported that replacement cement by bottom ash (BA) up to 30% can increase the k-value of autoclaved concrete around 5% [19]. The concrete with thermal properties such as low thermal conductivity, low thermal diffusivity, and high specific heat capacity is desirable for using insulation in buildings construction [20].

Despite the available literature regarding the thermal properties of concrete while cement or aggregate is replaced, there is no information about the thermal properties of different strength class of normal weight concrete. Also, the most existing prediction models to predict thermal properties of concrete is about predicting mostly thermal conductivity, however, most of the proposed equations are valid for lightweight concretes. The different grades of normal weight concrete have various mix proportions and may differ in some

Corresponding author: Brit Anak Kayan, University of Malaya, 50603 Kuala Lumpur, Malaysia. E-mail: brit284@um.edu.my.

ingredients. Therefore, it is expected that different grades of normal weight concrete have different thermal properties.

This study aim is to consider thermal properties (thermal conductivity, specific heat capacity, and thermal diffusivity) of different grades of concrete with different mix proportions while the type of coarse aggregate, fine aggregate, cement, curing condition, and testing methods were the same. In addition, due to the measuring of thermal properties of cement-based materials require special equipment and test setups, this study presents equations to predict the thermal properties based on physical/mechanical properties.

2 Experimental program

2.1 Materials

In this study the ordinary Portland cement (OPC), confirming the requirement of MS522 part 1:2003 with compressive strengths of 36 MPa at 7days and 48 MPa at 28 days has been used. The 89 specific gravity and specific surface area of the used OPC are 3.2 and 3510 cm^2/g, respectively Table 1.

Table 1: The composition details of OPC (% by mass)

Chemical composition	OPC
Cao	63.40
SiO_2	19.80
Al_2O_3	5.10
Fe_2O_3	3.10
MgO	2.50
SO_3	2.40
K_2O	1.00
Na_2O	0.19
LOI	1.80

Also using from local mining sand with a saturated surface dry (SSD) specific gravity of 2.55, fineness modulus of 2.8, and water absorption of 1.5% was used in all mixtures. The water used in all mixes was potable water from the pipeline in the lab. The superplasticizer (SP) used is Sika Viscocrete-2192 from Sika Company. The (SP) used is a modified polycarboxylate type superplasticizer. Potable water, free from impurities and chemical contaminants was used for all mixes.

2.2 Mixtures proportions

In this study, fourteen different normal concrete (NC) mixtures were used. Variables include cement content, water to cement ratio, fine and coarse aggregate contents to prepare different resistive grades of NC without using cementitious materials. The applied cement content ratio was in the range of 280 to 570 kg/m^3. To achieve low and high grades of concretes W/C ratio was increased or superplasticizer used this ratio. The W/C ratio varied between 0.34 and 0.94. The mix proportion of all NC are given in Table 2.

2.3 Testing methods

2.3.1 Compressive strength

The compressive strength test was measured according to the ASTM C39 at 7 and 28 days. A compressive strength test was carried out on cubic specimens with 100 mm^3. The cubic specimens were removed from the molds after 1 day and were cured in normal water till the test of 7 and 28 days.

2.3.2 Oven dry density

Oven dry density test was cubic samples were dried at the oven for 24 hours after curing. The samples were taken out from the oven and wait to get cold for a few minutes. After that they weighted, and the exact dimension was measured by calipers.

2.3.3 Water absorption

The water absorption test values were measured according to ASTM C642. The water absorption test was conducted on 100 mm^3 cubic specimens. The saturated surface dry specimens were dried in an oven at 105 ± 5 ℃ for 24 hrs. Dry weight (A) was then recorded. Afterward, the specimens were immersed in water at 20 ℃ until they achieved a constant weight (B). The absorption at 30 min (initial absorption) and 72 hrs (final water absorption), when the difference between two consecutive weights was almost negligible, were calculated by the following formula:

$$\textit{Water absorption (\%)} = [(B-A)/A] \times 100 \qquad \text{(Eq. 1)}$$

2.3.4 Sorptivity

The sorptivity test values were measured by ASTM C1585. The Sorptivity test was carried out on the 100 mm^3 cube samples at the age of 28days. The weight of all samples was measured before testing. The infused water in a tray in a depth of 2mm of the tray. The samples put on rods with a 1 mm diameter inside the tray. The weight of the samples was measured after 5, 10, 30, 60, and 120 minutes. The sorptivity was calculated by the following formula:

$$S = \frac{i}{\sqrt{t}} \qquad \text{(Eq. 2)}$$

where S ($g/mm^2/min^{1/2}$) is the sorptivity coefficient, i (g/mm^2) represents the cumulative amount of water absorbed per unit cross-sectional, and t represents the time measured in minutes.

2.3.5 Thermal conductivity

Based on [21, 22] used from thermal conductivity were determined by the KD2-Pro thermal conductivity analyzer in compliance with the ASTM D 5334. In this study, three cylindrical specimens (100mm * 200mm) at the age of 28 days were selected to measure thermal conductivity at dry conditions. The samples were oven-dried for 24 hours in the degree of 100 ± 5 ˚C to remove all moisture. The k-value of specimens was determined with KD2-PRO analyzer using TR1 needle. TR1 sensor with (2.4 mm in diameter and 100 mm in length) is capable to measure thermal conductivity in the range of 0.1 W/m.K to 4 W/m.K [23]. A pilot pin was inserted to the uncured specimens to prepare the hole in the size of TR1 sensor. The 10 minutes reading of sensor and 15 minutes interval, contribute to minimize errors derived from the large diameter needle. The theory of KD2-PRO analyzer is based on heating the needle for a time and monitoring the temperature during heating and cooling. The influence of ambient temperature on samples should be kept as minimum as possible to achieve more accurate value while using KD2-PRO. Therefore, the surface of specimens was wrapped by plastic bags to minimize the effect of ambient temperature as can be seen in Figure 1.

2.3.6 Specific heat capacity

The specific heat capacity was measured based on the method used by [24]. One foam ice box was prepared as a calorimeter. The temperature changing of the 42 °C water was 0 .8 °C in one hour, which demonstrated the box was well insulated very well.

Table 2: The mixtures proportion details

Mix No.	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse Aggregate (kg)	W/C (%)	SP (gr)
NC1	280	262	856	896	0.94	0
NC2	380	280	890	927	0.74	0
NC3	360	247	906	955	0.69	64
NC4	360	190	923	970	0.53	192
NC5	397	274	800	880	0.69	0
NC6	397	200	826	907	0.50	90
NC7	381	280	808	891	0.73	0
NC8	435	356	740	813	0.82	0
NC9	447	248	790	870	0.55	90
NC10	435	270	786	770	0.62	0
NC11	500	300	720	828	0.60	0
NC12	500	250	743	851	0.50	75
NC13	570	200	715	756	0.35	130
NC14	500	172	798	880	0.34	420

Figure 1: Thermal conductivity measurement process

The specific heat capacity test carried on three cylindrical specimens with 100 mm diameter after 28 days of water curing. One piece of each oven-dried sample was cut and kept at room temperature for 24 hours. The mass and temperature of the water were measured. Then, the surface temperature and weight of normal concrete specimens were measured. After that, the samples were immersed to the calorimeter and the changing temperature was monitored through available thermometer inside the box as shown in Fig. 2. The equivalent temperature was achieved in less than 1 hour for all samples. By considering the changing temperature of water (0.8 °C/h), the specific heat of normal concrete was calculated using the following equation:

$$C_{cm} = \frac{m_w \, C_w (T_w - T_e)}{m_{cm} \, (T_e - T_{cm})} \quad \text{(Eq. 3)}$$

where C_{cm} and C_w are the specific heat of concrete and water (kJ/kg. K), m_{cm} and m_w are the mass of concrete and water (kg) and T_{cm}, T_w and T_e are the temperature of concrete and water and equal temperature °C, respectively.

2.3.7 Thermal diffusivity

Besides thermal conductivity and specific heat capacity, another significant property of transient heat transfer is thermal diffusivity (α). Thermal diffusivity, which expresses the rate of heat spread through materials. The following equation has been used to calculate the thermal diffusivity of concrete:

$$\alpha = \frac{K}{\rho C} \quad \text{(Eq. 4)}$$

where, α is the thermal diffusivity (m^2 /s), K is the thermal conductivity of a material (W/m.K), ρ is the density (kg/m^3) and C is the specific heat (J/kg.K).


Figure 2: Specific heat capacity measurement process

3 Results and discussion

3.1 Thermal properties

Thermal properties of normal concrete like thermal conductivity, specific heat capacity and thermal diffusivity. The measured thermal properties for different grades of normal concrete are presented in Table 3.

3.1.1 Thermal conductivity (k)

Thermal conductivity is the property of material pertaining to heat conduction. The results indicate that thermal conductivity for normal concrete is found in the range of 1.6 to 3.2 W/m.K, also reported the standard range normal concrete of around 1.4 to 3.6 W/m.K [25]. As can be seen in Fig.3 the thermal conductivity value of increased significantly when the cement amount increasing. The thermal conductivity of NC1 containing 280 (kg) of cement is around 50% less than the sample NC13 containing 570 (kg) of cement. This may be happened due to the nature of cement. The congestion can effect on thermal conductivity of concrete significantly. The thermal conductivity of concrete changes depending these voids are filled with water. The previous studies revealed that the thermal conductivity of cement-based materials to water/cement (w/c) ratio decreased, the thermal conductivities of the specimens increased [26]. The sample NC13 has a higher thermal conductivity with the lowest (w/c) amount compared to other samples.

3.1.2 Specific heat capacity (C_p)

The measured specific heat capacity of this study was 0.92 kJ/kg.K to 1.16 kJ/kg.K at room temperature, respectively. Fig.4 represents the comparison between measured specific heat capacity value and water to cement (W/C) ratio.The results indicated that the specific heat capacity of increased significantly when the water to cement ratio increasing. The sample NC14 with the lower specific heat capacity 0.92 KJ/kg.K has the lowest water to cement ratio among all samples. The specific heat capacity of sample NC1 is around 11.5% more than of NC14.

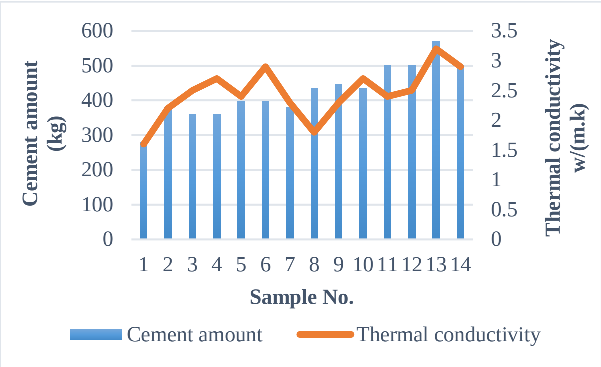

Figure 3: The comparison between thermal conductivity value and cement amount.

Table 3: Thermal properties of concretes

Sample ID	Thermal conductivity W/(m. K)	Specific heat capacity (kJ/kg. K)	Thermal diffusivity (* 10^{-6} m^2/s)
NC1	1.6	1.04	0.69
NC2	2.2	1.10	0.87
NC3	2.5	1.00	1.06
NC4	2.7	0.95	1.19
NC5	2.4	1.04	1.0
NC6	2.9	1.01	1.18
NC7	2.3	0.99	1.02
NC8	1.8	1.16	0.70
NC9	2.3	1.03	0.93
NC10	2.7	0.94	1.20
NC11	2.4	1.11	0.94
NC12	2.5	1.04	1.01
NC13	3.2	0.95	1.34
NC14	2.9	0.92	1.29

3.1.3 Thermal diffusivity (α)

Thermal diffusivity of concrete indicates its capability in transient heat conduction. The thermal diffusivity of normal concrete contain the different mix proportions were different in thermal conductivity and specific heat capacity. The normal concrete with low thermal diffusivity is considered as a heat insulation in transient heat transfer conditions. The thermal diffusivity of sample NC13 in comparison with sample NC1 was reduced 47%.

3.2 Compressive strength

The compressive strength, also known as crushing strength was obtained by dividing the maximum load applied over the concrete contact surface area. The compressive strength for all the tested samples illustrates in Fig 5. The compressive strength was found in a range of 10.6 MPa to 51.2 MPa and 15.8 MPa to 62.1 MPa for 7 and 28 days respectively. The concrete samples have a compressive strength of a wide range for different types of normal concrete. Though the compressive strength of 7 days fulfills the requirement for normal concrete, higher strength of 28 days about 62.1 MPa is preferred for strength structural members. Previously study reported the compressive strengths normal concrete 7 and 28 days 32.8 and 43.4 MPa, respectively. In comparing with sample NC13 with same mixed proportion sample NC13 has better than the result.

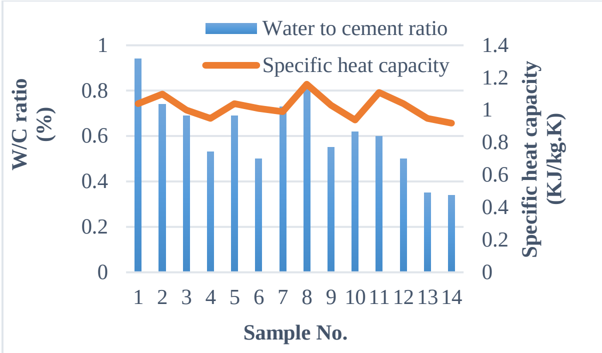

Figure 4: The comparison between specific heat capacity value and water to cement ratio

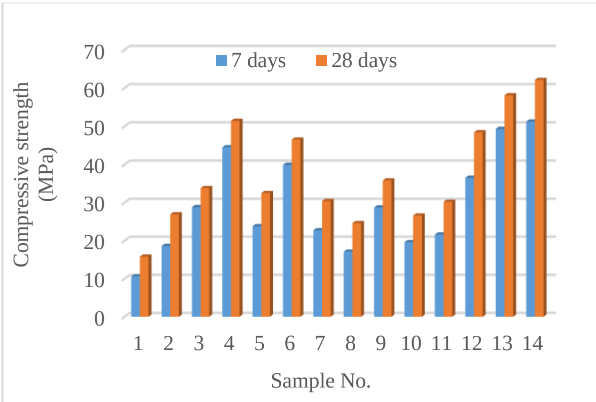

Figure 5: The results from the compressive strength test for 7 and 28 days ages.

Fig. 6 depicts the relation between the thermal conductivity of normal concrete and its compressive strength. The results indicate that the thermal conductivity increased by compressive strength increment. However, as a result, the specific heat capacity reduced when compressive strength increased. The development of a prediction model for thermal properties of concretes from compressive strength is important due to testing of concrete material is easier, as it is a basic and important mechanical property, than all testing methods for the thermal properties. However, as can be seen in Fig.6, R^2 correlation between thermal conductivity and compressive strength is good, meaning that this thermal property can be predicted from compressive strength with good accuracy.

3.3 Oven dry density

The oven dry density at 28-days for all the samples is provided in Fig 7. The normal concrete density varied from 2205 kg/m^3 to 2498 kg/m^3. The results specified that the sample NC8 and sample NC13 have the lowest and highest oven dry density, respectively. Fig.8 shows the relation between thermal conductivity and oven dry density of normal weight concret. The results show that the thermal conductivity of normal concrete increase by increment the density. As a result, the normal concrete with lower densities is better insulation materials either in steady and transient thermal conditions due to their lower thermal conductivity and thermal diffusivity, respectively.

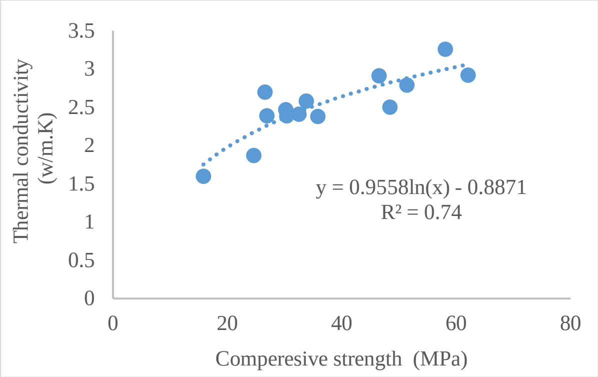

Figure 6: The relation between thermal conductivity and compressive strength of normal weight concrete

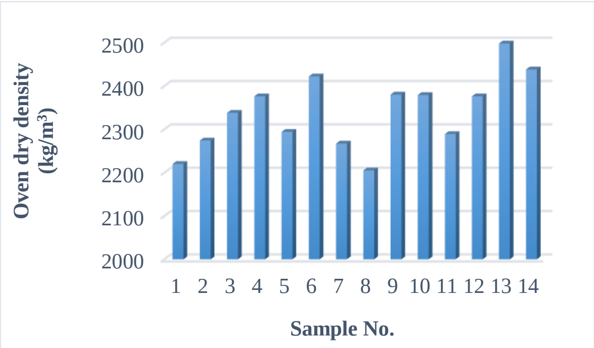

Figure 7: The results from oven dry density test, age 28 days

It has been shown from previous studies that concrete density has the best relationship with the thermal conductivity of concrete. Therefore, many researchers attempted to find a relationship between thermal properties and the density of concrete [7].

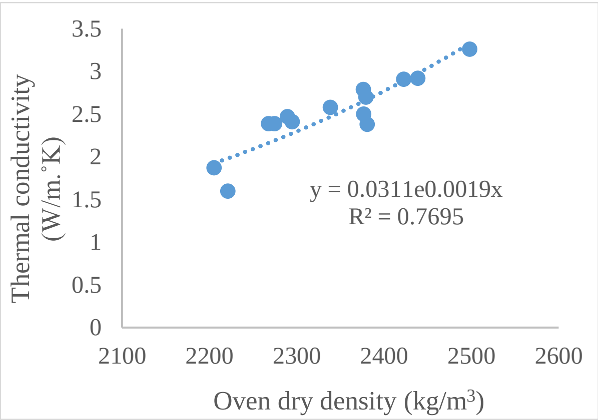

Figure 8: The relation between thermal conductivity and the oven dry density of normal weight concrete

3.4 Water absorption

Fig.9 shows the initial and final water absorption of normal concrete different mix proportion at the age of 28-day. It was observed that the initial and final water absorption of all samples is in the range of 0.4% to 2.9% and 1.1% to 5.7%, respectively. As can be seen, samples NC1 and NC13 have the highest and lowest initial and final water absorption, respectively. According to the literature, the quantified that cement-based materials with the initial water absorption values of more than 5%, 3 to 5%, and below 3% are classified as poor, average, and good in quality [27].

According to the relation between water absorption with porosity the material, there should be a relation between water absorption and thermal properties of normal concrete. As shown in Fig.8, there is a correlation between water absorption and thermal conductivity of normal weight concrete. Both thermal conductivity and thermal diffusivity of normal concrete decreased by the increment of water absorptions. It indicates the slower speed of heat transfer is among the samples with higher water absorption. It is due to the porosity inside the concrete samples. A concrete with higher porosities has higher water absorption and consequently has lower k-value. Therefore, it can be seen that it is possible to find a prediction model for the thermal properties of concrete from the water absorption test. As can be seen in Fig.10, depicts the relation between the thermal conductivity of normal weight concrete and water absorption.

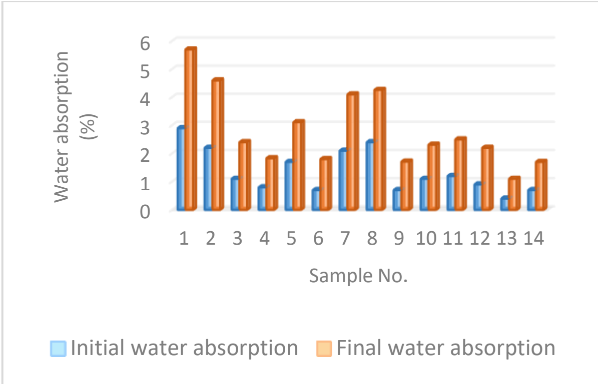

Figure 9: Initial and final water absorption

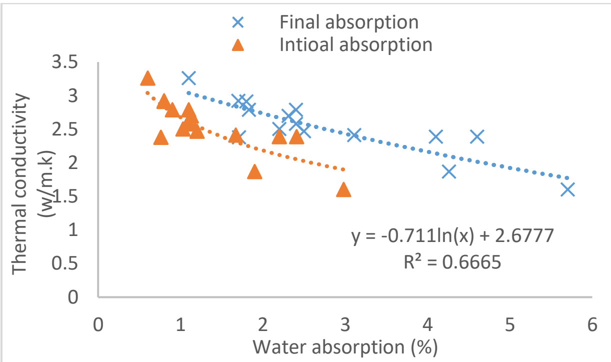

Figure 10: The relation between thermal conductivity and water absorption of normal weight concrete

3.5 Sorptivity

The sorptivity test determined by the measurement of the capillary rise absorb rate on defined times. The cumulative value of water absorbed per unit section area of samples are summarized in Fig 11. The results demonstrate that absorbed water was increased along with the measured times.It is shown that all samples has different water absorbed per unit area. Fig. 12 show the relation between thermal conductivity and sorptivity of normal weight concrete. The findings result in a close relation between normal concrete sorptivity and thermal properties. Thermal conductivity of normal concrete decreased by the increment of sorptivity. It indicates that higher sorptivity cause the ideal thermal conductivity of normal concrete.

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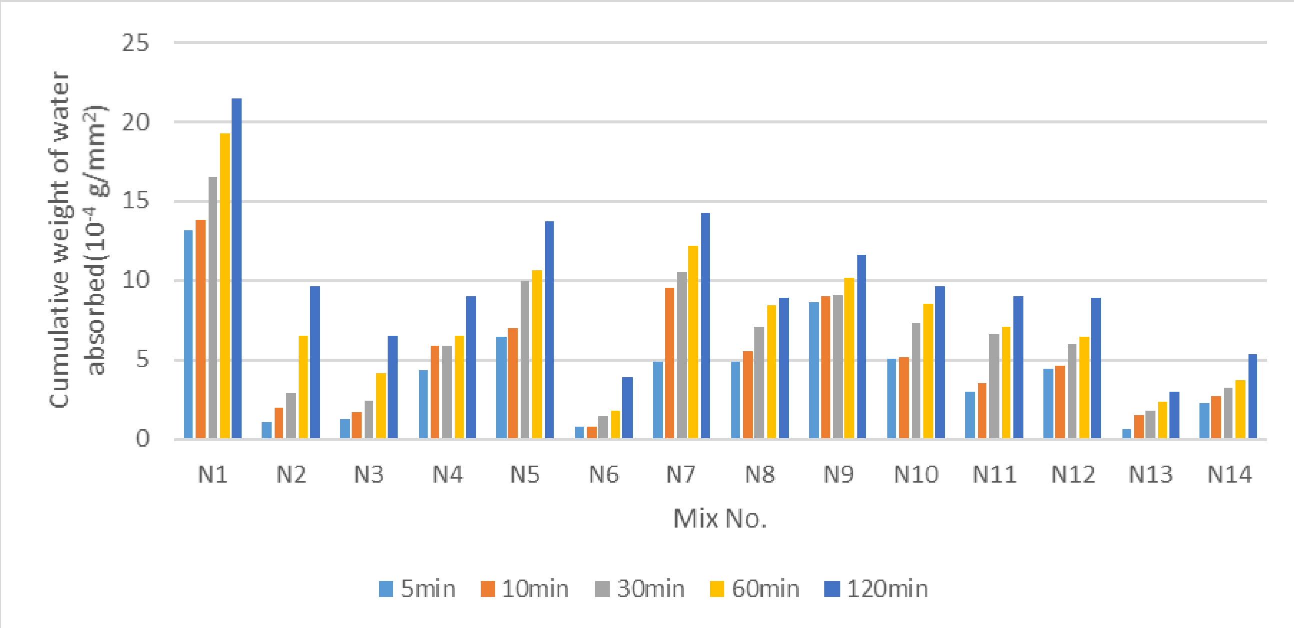

Figure 11: The surface water absorption

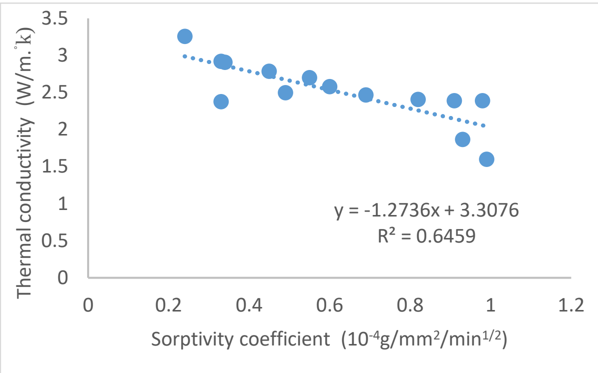

Figure 12: The relation between thermal conductivity and sorptivity of normal weight concrete

4 Conclusions

The main aim of this research is investigation of thermal properties of normal weight concrete for different strength classes. This study assessed the effect of different strength classes on thermal properties of normal weight concrete. Furthermore, the relationship between thermal properties with mechanical and physical properties of normal concrete was investigated. The findings show the normal concrete as a sustainable construction material is able to reduce heat transfer and energy consumption. The following conclusions can be made based on the experimental results obtained in this study:

- The thermal conductivity and thermal diffusivity increases while the lower amount of (w/c) ratio has been applied. The thermal conductivity and thermal diffusivity of sample NC13 have increased by 50%, 48.5% compared to NC1, respectively.
- The increment of cement and decrease of water to cement (w/c) in samples caused the increase in compressive strength. Using cement 280 kg to 570 kg increment the 7-day compressive strength 79.2% and also, the 28-day compressive strength increment 74.5%. Results showed that the thermal conductivity and thermal diffusivity of concrete increased by increasing compressive strength. However, the compressive strength of normal concrete remains in the acceptable range for various applications in buildings.
- The previous studies and ACI model curve have overlapped with density this study from 2200 to 2500 (kg/m^3). However, the results thermal conductivity and thermal diffusivity of this study is more than previous studies and ACI model.
- Decreasing both initial and final water absorption increased the thermal conductivity and thermal diffusivity of normal concrete. This may be due to the decreasing water to cement ratio. The reduction process initial and final water absorption was 2.9% to 0.4% and 5.7% to 1.1%, respectively.
- The thermal conductivity and thermal diffusivity of normal concrete decreased when the Sorptivity is increased. The higher sorptivity causes better thermal conductivity and thermal diffusivity of normal concrete.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

References

1. Maqbool, S.M., Bilal, A., Arshad, A., Rehan, A.M., Awais, A .Reuse of Wastes in Concrete. Journal of Environmental Treatment techniques; 2017. 118-123.

2. Zhang, D., Li, Z., Zhou, J. and Wu, K. Development of thermal energy storage concrete. Cement and concrete research; 2004.34(6), pp.927-934.
3. De Giuli, V., Da Pos, O. and De Carli, M. Indoor environmental quality and pupil perception in Italian primary schools. Building and Environment; 2012.56, pp.335-345.
4. Oktay, H., Yumrutaş, R. and Akpolat, A. Mechanical and thermophysical properties of lightweight aggregate concretes. Construction and Building Materials; 2015. 96, pp.217-225.
5. Meyer, C. The greening of the concrete industry. Cement and concrete composites; 2009.31(8), pp.601-605.
6. Monteiro, P. Concrete: microstructure, properties, and materials. McGraw-Hill Publishing; 2006.
7. Asadi, I., Shafigh, P., Hassan, Z.F.B.A. and Mahyuddin, N.B. Thermal conductivity of concrete–A review. Journal of Building Engineering; 2018. 20, pp.81-93.
8. Bhattacharjee, B. and Krishnamoorthy, S. Permeable porosity and thermal conductivity of construction materials. Journal of Materials in civil Engineering; 2004.16(4), pp.322-330.
9. Chan, J. Thermal properties of concrete with different Swedish aggregate materials. Rapport TVBM (5000-serie); 2014.
10. Khan, M.I. Factors affecting the thermal properties of concrete and applicability of its prediction models. Building and Environment; 2002.37(6), pp.607-614.
11. Holm, T.A. and Bremner, T.W. State-of-the-art report on high-strength, high-durability structural low-density concrete for applications in severe marine environments. US Army Corps of Engineers, Engineer Research and Development Center; 2000.
12. Newman, J. and Owens, P. Properties of lightweight concrete. Advanced concrete technology; 2003. 3, pp.1-29.
13. Real, S., Gomes, M.G., Rodrigues, A.M. and Bogas, J.A. Contribution of structural lightweight aggregate concrete to the reduction of thermal bridging effect in buildings. Construction and Building Materials; 2016. 121, pp.460-470.
14. Yun, T.S., Jeong, Y.J., Han, T.S. and Youm, K.S. Evaluation of thermal conductivity for thermally insulated concretes. Energy and Buildings; 2013. 61, pp.125-132.
15. Wu, Y., Wang, J.Y., Monteiro, P.J. and Zhang, M.H. Development of ultra-lightweight cement composites with low thermal conductivity and high specific strength for energy efficient buildings. Construction and Building Materials; 2015. 87, pp.100-112.
16. Huang, X., Ranade, R., Zhang, Q., Ni, W. and Li, V.C. Mechanical and thermal properties of green lightweight engineered cementitious composites. Construction and Building Materials ;2013. 48, pp.954-960.
17. Öztürk, T. and Bayrakl, M. The possibilities of using tobacco wastes in producing lightweight concrete. Agricultural Engineering International: CIGR Journal; 2005.
18. Howlader, M.K., Rashid, M.H., Mallick, D. and Haque, T. Effects of aggregate types on thermal properties of concrete. ARPN Journal of Engineering and applied sciences; 2012. 7(7), pp.900-906.
19. Wongkeo, W., Thongsanitgarn, P., Pimraksa, K. and Chaipanich, A. Compressive strength, flexural strength and thermal conductivity of autoclaved concrete block made using bottom ash as cement replacement materials. Materials & Design; 2012.35, pp.434-439.
20. Demirboğa, R. and Gül, R. Thermal conductivity and compressive strength of expanded perlite aggregate concrete with mineral admixtures. Energy and Buildings; 2003. 35(11), pp.1155-1159.
21. Muhammad Riaz ahmad, Bing Chen, M. Aminul Haque, Sajjad Yousefi Oderji. Multiproperty characterization of cleaner and energy-efficient vegetal concrete based on one-part geopolymer binder. Journal of Cleaner Production; 2020. 253, 119916.
22. A. Font, L. Soriano, J. Monzó, J.C.B. Moraes, M.V. Borrachero, J. Payá. Salt slag recycled by-products in high insulation alternative environmentally friendly cellular concrete manufacturing. Construction and Building Materials; 2020. 231, 117114.
23. C.S. Blazquez, A.F. Martín, I.M. Nieto, P.C.García, L. S. S. Perez, D.Gonzalez-Aguilera. Analysis and study of different grouting materials in vertical geothermal closed-loop systems. Renewable Energy; 2017.114: p. 1189-1200.
24. M.R. Islam, R.A. Tarefder. Determining thermal properties of asphalt concrete usingfield data and laboratory testing, Constr. Build. Mater; 2014.67, 297–306.
25. A.M. Neville, J.J. Brooks, Concrete Technology, second edition., Longman Scientific & Technical, England; 2010.
26. Daehoon. K, Gyoungman .K, Donghui .K, Hwanjo .B. Experimental and numerical investigation of thermal properties ofcement-based grouts used for vertical ground heat exchanger. Journal of Renewable Energy; 2017.112, 260-267.
27. Aprianti, E., Shafigh, P., Zawawi, R., Hassan, Z.F.B.A. Introducing an effective curing method for mortar containing highvolume cementitious materials. Construction and Building Materials; 2016. 365-377.