An Investigation into the Thermal Performance of Rubber-Concrete

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Abstract

The Thermal properties of concrete incorporating pulverized automobile tires as partial replacement for mineral coarse aggregate (granite) was investigated in other to assess its suitability as a construction material and also a solution to the environmental problems constituted by non-biodegradable waste tires. Replacement was made at: 5%, 10%, 15%, 20% and 25% by volume. Thermal properties were measured base on the transient line heat source (TLS) method using a KD 2 Pro thermal analyzer. Thermal properties most especially the thermal conductivity of concrete (1.816W/mk) have been greatly reduced to 1.283W/mk indicating 29.4% reduction after 25% partial replacement of mineral aggregate with the rubber particles which makes it a better insulator while the specific heat capacity of concrete (3.040 MJ/m3.k) have been reduced to 2.137MJ/m3k indicating 29.7% reduction with same 25% rubber particles which may adversely reduce thermal mass effect. Other thermal properties such as thermal resistivity increased by 29.4%, thermal diffusivity decreases by 65.1% while thermal effusivity decreases by 37.6% with 25% rubber particles content in concrete. The result indicates that the potential use of such composite material for building applications is viable.

Keywords: *Concrete, Workability, Density, Strength, Thermal Performance*

1. Introduction

Enormous quantities of solid waste materials are generated all over the world every year and are classified into hazardous and non-hazardous waste materials. As the population of the world grows so does the amount and type of waste materials generated.

One of such materials is automobile waste tyres which are non-biodegradable.

According to Yang *et al.,* (2000), each year about 9 million tonnes waste rubber-tyres are disposed of all over the world, which was also estimated to be around 1 billion tyres withdrawn from use in the world annually Erdogan *et al.,*(2010).

Ebewele *et al.,* (1990) reported that an estimated 5 million scrap tyres from trucks, cars and motorcycles existed in Nigeria in 1983 with an annual generation rate of 15% each year. About 21, million scrap tyres are estimated to exist in Nigeria by 2011.

In Nigeria today one of the most common ways of disposing waste tyres is through open field disposal, open air combustion most especially in our abattoir and local commercial quarry where they serve as source of fire for processing slaughtered animals and mining activities. These disposal methods produce greenhouse gases such as H_2, CO, CO_2, C_4H_6, CH_4 and C_2H_6 with lower concentration of other hydrocarbon gases which are responsible for the depletion of the ozone layer hence contributing to global warming (Rise in temperature of the atmosphere) and also polluting the earth and ground water. Burning waste tyres piles up char residue without any possible disposal means.

Scientists, engineers and technologists look out for using different types of solid waste as alternative for some ingredients of civil engineering materials such as asphalt and concrete Khalid *et al.,*(2008). Many researchers have studied and developed various recycling methods for re-use of waste rubber-tyres in construction materials. Some of these methods are: use of waste rubber-tyres in asphalt concrete mixture; use of waste rubber-tyres in some plastic and rubber products; utilizing waste rubber-tyres in Portland cement concrete; use of waste rubber-tyres as a visco-elastic material for vibration dampers and utilizing waste rubber-tyres in ordinary cement mortar Yunping *et al.,* (2010).

Early studies on the use of waste rubber-tyres in asphalt mixes, sealants and rubber sheets were very promising. They showed that rubberized asphalt had better skid resistance, reduce fatigue cracking and achieved longer pavement life than conventional asphalt (Adams *et al*., 1985; Esch 1984; Estakhri 1990; Khosla and Trogdon 1990).

Thermal properties of most cementitious materials are found to change with the presence of admixtures (Cisse and Laguerbe, 2000; Okpala, 1993). The change is found to depend on the admixture's grain structure or interstitial arrangement within the main material and other micro structural parameters including the volumetric fraction of each constituent, the shape of the particles, and the size distribution of the particles. The thermal properties that influence the temperature rise and distribution in a concrete structural section are: Thermal conductivity, Specific heat capacity, Thermal expansion and Mass loss (Neville, 1996). These properties depend on the type of aggregate, aggregate fraction temperature, composition of the concrete mix with admixture (if any) and method of curing.

The inclusion of processed waste rubber-tyre in concrete could also make the material a better thermal insulator, due to better thermal insulating properties of rubber-tyre which could be very useful especially in the wake of energy conservation requirements Tantala *et al.,* (1996). However, there are currently very few projects reported in the literature which investigated this possibility. Today's wide range of conventional and alternative concretes has wide range thermal properties. Therefore these research further extend to look into its thermal capabilities of Rubber-Concrete to efficiently exploit thermal performance in relation to conductivity, resistivity, diffusivity, heat capacity and effiusivity also understanding of these and their application across spectrum imperative. Shin *et al.,* (2002) investigated the thermal properties of concrete at elevated temperature and reported that the thermal properties of concrete depend on the thermal properties of the aggregates. Khan *et al* (2001) reported that the thermal conductivity in dry and wet limestone concrete being 1.6W/m^{o}c and 2.7W/m^{o}c respectively while for siliceous aggregate concrete the value are 3.5W/m^{o}c and 2.3W/m^{o}c.

Benazzouk *et al.,*(2008). conducted an investigation of the thermal conductivity of a lightweight construction material containing rubber waste particles which measurement were carried out in a dry state using a transient plane source (TPS) technique. The effect of the rubber particles ratio on the thermal conductivity of cement composite, 10%, 20%, 30%, 40% and 50% rubber particles ratios by volume as replacement to cement were used. The experiment investigation revealed that the addition of rubber particles reduces the material unit weight; furthermore, thermal conductivity of the composite has been improved.

2. Materials and Methods

2.1 Materials

Rubber-Concrete (RC) consists of cement, natural aggregate (fine and coarse), waste ground rubber-tyre derived aggregate and water. Ordinary Portland Cement (OPC) with specific gravity of 3.15 was used throughout the investigation which was sourced from a retail outlet and tested to ensure that it conforms to BS 12: 1991. Ordinary tap water (potable drinking water) which is fresh, colourless, odourless, tasteless and free from organic matter of any kind sourced from Civil Engineering Laboratory Ahmadu Bello University, Zaria Nigeria was used for all concrete mixes and curing. The water is therefore fit for concrete work (BS 3148:1980).Natural sharp river quartzite sand smaller than 4.76mm but larger than 75µm that is free of clay, loam, dirt and any organic or chemical matter with average specific gravity (SSD) of 2.65 and bulk density of 1,454.55Kg/m^3 was used as fine aggregate. The fine aggregate (sand) falls in zone two (medium sand) according to BS 882 specification. Natural crushed (granite) with nominal maximum sizes of 19-20mm (3/4inch) sourced from a local commercial quarry with average specific gravity (SSD) of 2.67 and bulk density of 1500kg/m^3 was used as coarse aggregate. Coarse rubber aggregate (ground rubber) from scrap tyres with nominal maximum sizes of 19-20mm (3/4inch), specific gravity of 1.14 and bulk density of 945Kg/m^3 was used for this research. The coating of ground rubber aggregate with cement paste was adopted for this research, as a surface treatment of the rubber aggregate it is a simple method of improving the strength performance of the material Kew *et.al.,* (2004) thereby avoiding the use of additional or costly additives which may adversely affect the production costs.

2.2 Mix Proportions

The mix design for the concrete was be based on an Absolute volume method according to BS 5328: Part 2: 1991, “Method of specifying concrete mixes”, Base on a preliminary estimate of the concrete mix design, a mix ratio of 1:2:4, Compressive strength of 30N/mm^2 at 28 days (Grade 30 Concrete) with water/cement ratio of 0.45 and aggregate/cement ratio of 4:1 was used to produce a trial mix which was tested for workability, strength, density and finishing properties and eventually subjected to adjustment and applied to all the concrete mixes. A total number of six (6) mixes were prepared: One control mixes with no ground rubber aggregate and five concrete mixes in which the 19-20 mm coarse aggregate (granite) was replaced by ground rubber aggregate at 5%, 10%, 15%, 20% and 25% by volume. The mix proportions was constant in terms of mix design ratio, water/cement ratio, sizes, type of natural and rubber-tyre aggregate used for the study. A total of 18 Concrete cubes for thermal test after 28 days of curing in water. Table1 and 2 below show the mix proportion.

Table 1: Quantity of Materials to 1m^3 of Concrete (Control Mix)

Mix Ratio	W/C Ratio	A/C Ratio	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
1:2:4	0.45	4	331.09	662.18	1,324.36	148.99

Table 2: Quantities of Materials to 12 No of Cube Moulds + 10% (Waste/Shrinkage) Per Mix Volume of 1 Cube Mould (100x100x100)mm=0.001m^3

Mix No	Mix Ratio	W/C Ratio	Rubber Aggregate (%)	Rubber Aggregate (Kg)	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Kg)
A	1:2:4	0.45	0	0	4.32	8.76	17.52	1.92
B	1:2:4	0.45	5	0.552	4.32	8.76	16.68	1.92
C	1:2:4	0.45	10	1.104	4.32	8.76	15.72	1.92
D	1:2:4	0.45	15	1.680	4.32	8.76	14.88	1.92
E	1:2:4	0.45	20	2.160	4.32	8.76	14.04	1.92
F	1:2:4	0.45	25	2.760	4.32	8.76	13.20	1.92

2.3 Testing of Concrete Cubes Samples

Tests were conducted to assess the workability of the freshly mixed concrete (Control mixes) and that of rubber-concrete mixes at the Department of Civil Engineering Concrete laboratory Ahmadu Bello University (A.B.U) Zaria. The test conducted includes: Slump test and Compacting factor test in accordance with BS 1881: Part 102 and 103:1983 respectively. The density of the hardened concrete were established in accordance with BS 1881:Part 114:1983 from the cube samples after 7,14 and 28 days of standard curing in water in accordance with BS 1881: Part 111:1983. The compressive strength tests of concrete samples were determined according to BS 1881: Part 116:1983 after 7, 14 and 28 days of standard curing in water. KD 2 PRO thermal properties analyzer from the Department of Geology, University of Ibadan (U.I) was used to measure the thermal conductivity *(k)*, thermal resistivity *(ρ)*, thermal diffusivity (α) and Volumetric Specific heat Capacity (c) of concrete cube samples after 28 days of standard curing in water; while the thermal effusivity *(β)* were computed from the relationship between thermal conductivity, density and specific heat capacity ($\beta = \sqrt{k\rho C}$).

2.4 KD 2 Pro Thermal Properties Analyzer Theory and Analysis (Transient Line Source Theory)

According to the KD2 Pro thermal properties analyzer operator's manual version 11 by Decagon Devices, Inc. (2011) and KD2 Pro Application Note 13945-01 (2009),The KD2 PRO is a handheld device that fully complies with ASTM D5334-08 and used to measure thermal properties of materials which is based on probe/sensor (Transient line heat source) methods. It consists of a handheld controller and sensors probe that can be inserted into the medium you wish to measure. The probe is allowed enough time to attain the uniform temperature of the specimen before the heater was energized. The single-needle sensors measure thermal conductivity and resistivity; while the dual-needle sensor also measures volumetric specific heat capacity and diffusivity.

A pilot hole were mould in wet concrete mix using the pilot pins furnished with the KD2 Pro using the following procedure: pilot pin were coated with Vaseline, pin were installed at least 80mm deep while concrete is wet, the pin were removed when concrete has dried. The single (TR-1) and the dual (SH-1) needle probe senor were coated with thermal grease in other to enhance (good contact with the concrete walls), sensor was then inserted into to the cast hole and readings were taken from the handheld meter. KD2 Pro Thermal Properties analyzer calculates its value for thermal conductivity, resistivity and diffusivity base on Transient line heat source methods which have been used for over 50 years to measure thermal conductivity of porous materials. The idea behind the transient method is to determine thermal conductivity, using a rate of temperature change in response to an applied heat source. The apparatus is at a constant initial temperature. During the course of the measurement, a known amount of heat produced by the line-source, results in a heat wave which propagates radially into the specimen. The rate of heat propagation is related to the thermal diffusivity of the material. The temperature rise of the line-source varies linearly with the logarithm of time. Typically a probe for this measurement consists of a needle with a heater and temperature sensor inside. A current is passed through the heater and the temperature of the probe is monitored over time. An analysis of the probe temperature is used to determine thermal conductivity. In the dual probe the analysis of the temperature against time relationship for the separated probes yields information on diffusivity and heat capacity as well as conductivity.

Equation for radial heat conduction in a homogeneous, isotropic medium is given by:

$$\frac{\partial T}{\partial t} = \alpha\left\{\frac{\partial^2 T}{\partial r^2} + r^{-1}\frac{\partial T}{\partial r}\right\} \qquad (1)$$

Where T is temperature (^oC), t is time (s), α is the thermal diffusivity (m^2/s), and r is radial distance (m).

If heat at a constant rate, *q* is applied to an infinitely long and infinitely small "line" source, the temperature response of the source over time can be described by the equation:

$$\Delta T = -\frac{q}{4\pi k} Ei\left(\frac{-r^2}{4Dt}\right) \qquad (2)$$

Where *k* is the thermal conductivity of the medium in which the line is buried, *D* is the thermal diffusivity of the medium, *r* is the distance from the line at which temperature is measured, and *Ei* is the exponential integral. *Ei* is defined in the following equation, and can be approximated by the series shown:

$$-Ei(-\alpha) = \int_{\alpha}^{\infty} (1/u)\exp(-u)du = -\gamma - \ln\alpha + \alpha - \alpha^2/4 + \ldots\ldots\ldots\ldots \qquad (3)$$

In which $\gamma = 0.5772\ldots\ldots$ is Euler's Gamma Constant and $\alpha = r^2/4Dt$

The terms beyond ln α in the series expansion of *Ei* become negligibly small for long times when *r* is small and *D* is large, so Equ 3 can be approximated as:

$$\Delta T \approx \frac{q}{4\pi k}\ln t + C \qquad (4)$$

Where *C* is a constant Thus, if early time data are ignored, a graph of ΔT vs. $\ln t$ becomes a straight line with slope equal to $q/4\pi k$ since two points define a straight line, *k* can be computed from:

$$k = \frac{q(\ln t_2 - \ln t_1)}{4\pi(\Delta T_2 - \Delta T_1)} \qquad (5)$$

The resistivity, *ρ,* is the reciprocal of *k*.

Assumptions of Equation (5)

This simplified equation rests on three assumptions:

1. That the exponential integral can be approximated by the logarithm.
2. That the probe is infinitely long and infinitely small.
3. That the ambient temperature is constant during measurement.

In reality, probes are neither infinitely long nor infinitely small. The ambient temperature of the sample is also never constant during a measurement; there is always some temperature drift.

Better Solution

A better solution to the differential equation for finite length and radius probes can be obtained. For a heated cylindrical source of radius *a* (m) and length 2*b* (m), with temperature measured at its centre, the temperature rise during heating is:

$$\Delta T = \frac{q}{4\pi k}\int_{r^2/4Dt}^{\infty} u^{-1}\exp(-u)\exp\left[-(a/r)^2 u\right] I_o(2au/r)\, erf\left(\frac{b}{r}\sqrt{u}\right)du \qquad (6)$$

Here $I_o(x)$ represent a modified Bessel function of order zero, $erf(\ )$ is the error function, and u is an integration variable. The quantity $\exp\left[-(a/r)^2 u\right] I_o(2au/r)$ approaches unity as a/r approaches 0, and $erf\left(\frac{b}{r}\sqrt{u}\right)$ approaches unity as b/r approaches infinity. In these limits Equ. 6 becomes Equ 2.

2.4.1 Dual Needle Algorithm (SH-1)

Heat is applied to the heated needle for a set heating time, t_h, and temperature is measured in the monitoring needle, 6mm distant during heating and during the cooling period following heating. The readings are then processed by subtracting the ambient temperature at time 0, multiplying by 4π and dividing by the heat per unit length, q. The resulting data are fit to the following equations using a non-linear least squares procedure.

$$T^* = b_0 t + b_1 \left\{ E_i\left(\frac{b_2}{t}\right) - E_i\left(\frac{b_2}{t - t_h}\right) \right\} \quad (7)$$

$$T^* = b_0 t + b_1 E_i\left(\frac{b_2}{t}\right) \quad (8)$$

Where:

$$T^* = \frac{4\pi(T - T_o)}{q} \quad (9)$$

Here, Ei is the exponential integral Abramowitz and Stegun (1972), and b_0, b_1 and b_2 are the constants to be fit. T_0 is the temperature at the start of the measurement and q is the heat input. The first equation applies for the first t_h seconds, while the heat is on. The second equation applies when the heat is off. The thermal conductivity is computed from:

$$k = \frac{1}{b_1} \quad (10)$$

The Diffusivity is

$$D = \frac{r^2}{4b_2} \quad (11)$$

The conductivity and diffusivity are found by fitting Equ.8 to the transformed data. The correct values of b_o, b_1 and b_2 are the ones which minimize the sum of squares of error between the equations and the measurements. The values are found using the Marquardt (1963) non-linear least squares procedure. This procedure is susceptible to getting stuck in local minima and failing to find a global minimum in some problems (the single needle problem is a perfect example of a bad non-linear least squares problem) but the dual needle problem typically works well.

2.4.2 Single Needle Algorithm (TR-1)

Heat is applied to a single needle for a time, t_h, and temperature is monitored in that needle during heating and for an additional time equal to t_h after heating. TR-1 Needle used which is best for concrete (2.4 mm diameter and 100 mm long). The temperature during heating is computed from:

$$T = m_0 + m_2 t + m_3 \ln t \quad (12)$$

m_0 is the ambient temperature during heating (which could include some offset for contact resistance and the heating element being adjacent to the temperature sensor inside the needle), m_2 is the rate of background temperature drift, and m_3 is the slope of a line relating temperature rise to logarithm of temperature. During cooling the model is:

$$T = m_0 + m_2 t + m_3 \ln\left(\frac{t}{t - t_h}\right) \quad (13)$$

The thermal conductivity is computed from:

$$k = \frac{q}{4\pi m_3} \quad (14)$$

3. Results and Discussion

3.1 Thermal Properties

Thermal properties such as conductivity, heat capacity, diffusivity, resistivity and effusivity are critical in assessing the potential energy efficiency of rubber-concrete for both residential and commercial buildings application. Standard cubes (100x100x100)mm of concrete specimens were tested for the thermal properties using a KD2 Pro thermal Properties. Average results obtained from the experimental measurement of thermal properties of rubber-concrete are presented in Table 3 below

Table 3: Thermal Properties of Rubber-Concrete Cubes as a Function of Temperature (^{o}C)

Sample No	Density (Kg/m^3)	Temp ^{o}c	Mix Ratio (1:2:4) Water-Cement Ratio (W/C): 0.45				
			Thermal Properties @ 28 Days				
			Thermal Conductivity (W/mk)	Thermal Resistivity (Cm^{o}c/W)	Thermal Diffusivity (mm^2/S)	Heat Capacity (MJ/m^3.K)	Thermal Effusivity (W/m^{2}ks$^{1/2}$)
A 0%	2,483	33.53	1.816	55.07	0.919	3.040	3.702
B 5%	2,417	31.67	1.712	58.41	0.762	3.078	3.569
C 10%	2,333	30.32	1.594	62.74	0.647	2.737	3.190
D 15%	2,223	29.52	1.501	66.62	0.540	2.316	2.780
E 20%	2,117	27.93	1.374	72.78	0.454	2.242	2.554
F 25%	1,950	26.30	1.283	77.94	0.321	2.137	2.312

3.2 Effect on Thermal Conductivity (k) (Wm/k)

The effect of coarse (ground-rubber) aggregate on the thermal conductivity of concrete are presented in Table 3 which shows the variation with percentage rubber content, density and temperature. The results indicate that the value of concrete thermal conductivity decreases with an increase in the percentage of rubber aggregate thereby improving their insulating value (R-value) which is attractive and indicates high potentials for development most especially for tropical, temperate and cold climate where low thermal conductivity construction materials are desirable in optimizing the heating/cooling load within the building space and hence capacity of the mechanical equipment required in handling the load there by enhancing thermal comfort. Thermal Conductivity was also observed to increase with increase in density and temperature (Reversely Thermal conductivity decreases with decrease in density and temperature). This indicates that density, temperature and aggregate type can influence thermal conductivity. The control mixes (0% rubber mix) for concrete had a thermal conductivity of 1.816 W/mk compared to 1.712, 1.594, 1.501,1.374 and 1.283 W/mk for 5%, 10%, 15%, 20% and 25% rubber-concrete respectively. Thermal conductivity of concrete have been greatly reduced by 29.4% with 25% rubber particles content, which indicates a decrease in rate of heat transfer through the concrete making it a better insulator. The thermal conductivity of normal concrete is within the range of 1.5-3.5W/mk (Mindess, 2003).

3.3 Effect on Thermal Resistivity (ρ) (Cm^{o}c/W)

The inverse of thermal conductivity value (1/conductivity) provided the thermal resistivity which indicates the resistance to heat flow through unit thickness of the concrete with increase in percentage ground-rubber aggregate. Results(Table 3) show as expected that thermal resistivity increases with increase in rubber particles content in the concrete. Control mixes (0% rubber mix) for the concrete had a thermal resistivity of 55.07Cm^{o}c/w compared to 58.41, 62.74, 66.62, 72.78 and 77.94Cm^{o}c/w obtained for 5%, 10%, 15%, 20% and 25% rubber-concrete respectively. Thermal resistivity of concrete have been greatly enhanced by 29.4% with 25% rubber particles content, which indicates an increase in resistance to heat flow through the concrete making it a better insulator.

3.4 Effect on Volumetric Heat Capacity (C_v) (MJ/m^{3}k)

The heat capacity of the concrete reduces with increase in percentage replacement of rubber aggregate by volume of coarse aggregate (granite). The heat capacity of control mixes (0% rubber mix) measured was 3.040MJ/m^{3}k whereas 5%, 10%, 15%, 20% and 25% rubber-concrete have specific heat capacities of 3.078, 2.737, 2.316, 2.242 and 2.137 MJ/m^3k respectively. Heat capacity of concrete with 5% rubber particles content was observed to have increased slightly by 1.24% before a steady decline to 29.7% with higher rubber particles content up to 25%. Increase in specific heat capacity (heat energy storing capacity) signifies increase in thermal storage mass which is desired for heating building most especially in the cold climate but not much desired in temperate and hot climate while low specific heat capacity signifies lower thermal mass (reduction in heat storage capacity). In practical terms, it implies that in tropical and temperate climate these modified concrete composite will lose heat gained during the day faster, thereby enhancing thermal comfort within conferment of a building but for cold climate these will have an adverse effect because high heat storing capacity is always required in construction materials in other to store more heat which will aid in thermal cycle balance between the building and it environment there by keeping the residential and commercial buildings warm which reduces the cost of heating and CO_2 emission.

3.5 Effect on Thermal Diffusivity (α) (mm^2/s)

In a manner slightly similar with the thermal conductivity variation, the values of the thermal diffusivity of rubber-concrete is lower than that of the control mixes (0% rubber mix)as indicated in Table 3. The decreasing values of both density and the specific heat capacity of concrete with addition of rubber particles caused the thermal diffusivity value to decrease likewise. This effect implies that rubber-concrete will not undergo a faster temperature change or allow more rapid heat flow through it compared to the control mixes. Low thermal diffusivity also means a slower rate of heat transfer and a larger amount of heat storage. Material with low thermal diffusivity like the rubber-concrete will respond slowly to an imposed temperature difference and are effective thermal mass elements in a building (ACI 122R-02). The thermal diffusivity of control concrete mixes (0% rubber mix) measured was 0.919mm^2/s whereas 5%, 10%, 15%, 20% and 25% rubber-concrete have thermal diffusivity of 0.762, 0.647, 0.540, 0.454 and 0.321mm^2/s respectively. Thermal diffusivity of the concrete decreased by 65.1% with 25% rubber particles content, which implies a decline in the ability of the concrete to undergo a temperature change when exposed to a fluctuating thermal environment.Thermal performance is also characterized in terms of thermal diffusivity, for mass concrete applications. Concrete with a high thermal diffusivity will rapidly adjust its temperature to match that of its surroundings. Therefore, often a low thermal diffusivity is preferred so that the concrete may act as a heat sink/source to buffer temperature extremes experienced during a diurnal cycle Bentz *et al.*, (2011).

3.6 Effect on Thermal Effusivity (β) ($W/m^2Ks^{1/2}$)

The thermal effusivity values measured are presented in Table 3, the control concrete mixes (0% rubber mix) has 3.702 $W/m^2Ks^{1/2}$ whereas 5%, 10%, 15%, 20% and 25% rubber-concrete have thermal effusivity of 3.569, 3.190, 2.780, 2.554 and 2.312 $W/m^2Ks^{1/2}$ respectively. The result indicates that thermal effusivity of concrete decreases with the partial replacement of rubber aggregate by volume of coarse aggregate in concrete. Thermal effusivity of concrete have decreased by 37.6% with 25% rubber particles content, which indicates a reduction in the rate of heat absorption and release (heat exchange) of the composite material with its surrounding. In practical terms higher thermal effusivity of building materials increases its ability to conduct heat away from the building space faster thereby reducing the cooling load, and consequently increasing the period of thermal comfort. Low thermal effusivity such as the one obtained for rubber-concrete will reduce its ability to conduct heat away from the building faster thereby reducing heating load most especially in cold climates but will be a disadvantage for tropical climates such as Nigeria due to increase in cooling load which implies increase in cost.

4. Conclusions

The following conclusions are adduced on the thermal Properties of concrete when partially replaced by volume of natural granite.

i. Thermal diffusivity of concrete decreases by 65.1% with 25% rubber particles content, which implies a decline in the ability of the composite material to undergo a temperature change when exposed to a fluctuation thermal environment.
ii. Volumetric heat capacity of concrete with 5% rubber particles content increased slightly by 1.24% before a steady decline to 29.7% with higher percentage of rubber content up to 25%. These indicates a slight increase in heat storage capacity followed by a significant decline which is likely going to have an adverse effect on thermal mass (heat storing capability).
iii. Thermal effusivity of concrete is reduced by 37.6% with rubber particles content up to 25%, indicating a reduction in the rate of heat absorption and release (heat exchange) of the composite material with its surrounding.
iv. Temperature measured during the thermal test of concrete cube samples decreases from 33.53^{o}C to 26.30^{o}C indicating 21.6% decrease, which implies that increase in rubber particles decreases the temperature.
v. Thermal properties (conductivity, heat capacity, diffusivity and effusivity) of concrete increases with increase in density (unit weight) and temperature (reversely thermal properties decreases with reduction in density and temperature) with exception of thermal resistivity which is the inverse of thermal conductivity.

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