VOL. 7, NO. 7, JULY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECTS OF AGGREGATE TYPES ON THERMAL PROPERTIES OF CONCRETE

Milon K. Howlader, M. H. Rashid, Debashis Mallick and Tozammel Haque
Department of Civil Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh
E-Mail: milon_25@yahoo.com

ABSTRACT

The present research was designed to determine thermal properties of concrete manufactured by two different categories of coarse aggregates. For this rationale ninety six concrete cylinders of 100 × 200 mm were casted using burnt clay brick-chips and stone-chips as coarse aggregate with two different mixing ratios of 1:2:3 and 1:1.5:2. The specific heat and thermal diffusivity were measured by using semi-adiabatic calorimeter and CRD C 36-73 (heating and cooling of the samples) method, respectively. The thermal conductivity was also obtained by multiplying the specific heat, density and thermal diffusivity. From the experiment it was observed that the specific heat of concrete having burnt clay brick-chips is 13% greater than the concrete having stone-chips. Again the specific heat is 2 and 7% greater at lower mixing ratio than rich mixing ratio for brick-chips and stone-chips, respectively. In case of thermal diffusivity, concrete with stone-chips have 19% greater value than burnt clay brick-chips as coarse aggregate. Mixing ratio also have influence on thermal diffusivity and rich mixing ratio shows 42% and 22% greater values for brick-chips and stone-chips, respectively than lower mixing ratio. Thermal conductivity has a linear relationship with thermal diffusivity in both types of aggregates.

Keywords: concrete, specific heat, thermal diffusivity, thermal conductivity, density, coarse aggregates, mixing ratio.

INTRODUCTION

One of the main challenges in the design of concrete structures is to avoid the initiation of cracks regardless of the concrete element size, procedure of concreting, weather conditions and material properties used (Milovanovic, B. *et al*., 2011). The analysis of temperature and stress due to the hydration of concrete is very non-linear problem because a wide variety of time dependent boundary conditions and intensely time and temperature dependent thermal and mechanical properties of early-age concrete. Concrete is a multifaceted material and its properties can change dramatically when exposed to high temperatures (Fletcher, I. A. *et al*., 2007). Due to global warming, temperature increases quickly. As a result of urbanization, huge amount of carbon di-oxide (CO_2) and carbon monoxide (CO) are produced and causing global warming. For this purpose various civil engineering structures go through temperature changes. The development of high concrete temperatures could cause a number of effects that have been shown to be negative impact to long-term concrete performance.

High concrete temperatures intensify the rate of hydration, thermal stresses, the tendency for dehydrating shrinkage cracking, permeability, and reducing long-term concrete strengths, and durability which can lead to cracking on a microscopic or macroscopic scale (Schindler, A.K. *et al*., 2002; Mehta, P.K. *et al*., 2006). Hence, the concrete temperature during hardening is a key design consideration, especially since the time temperature history affects both strength and durability (De Schutter, G., 2001). Sometimes thermal insulating blankets were used in some construction projects to minimize the external and internal concrete temperature gradient (Whittier, S. *et al*., 2004). Generally, for controlling the crack, maximum temperature difference within the concrete mass should not go beyond 20°C (Neville, A. M., 1996), but with limestone aggregate, the difference can be permitted up to 31°C (Portland Cement Association 2003). So prediction of temperature rise of mass concrete is very essential for crack control analysis and design.

Under normal conditions, most concrete structures are exposed to a range of temperature no more severe than that enacted by ambient environmental conditions. However, in some important cases where these structures may be exposed to much higher temperatures (e.g., jet aircraft engine blasts, building fires, chemical and metallurgical industrial applications in which the concrete is in close proximity to furnaces, and some nuclear power-related postulated accident conditions) (Naus, D. J., 2005). A number of alterations and reactions occur in concrete made with Portland cement or blast furnace slag cement, in contact with heat, even if there is only a moderate increase in temperature (Schneider, U. *et al*., 1981, Bazant, Z. P., 1982). The cement paste undertakes an uninterrupted series of dehydration reactions as its temperature rises from 100°C (212°F) to about 850°C (1562°F). These reactions distress the thermal properties of the cement paste in three ways; (1) by the absorption of latent heats, (2) by the changes in the physicochemical characteristics of the solid matrix and, (3) by the changes in the porosity of the bulk material. The thermal conductivity depends on all three of these effects, while its dependence on the first is not satisfactorily understood (Zhuze, V. P. *et al*., 1969). The bulk density depends only on the second and third effects, and the specific heat only on the first and second.

As aggregate materials normally inhabit 65 to 75% of the concrete volume, the behavior of concrete at high temperature is strongly influenced by the aggregate type. Usually aggregate materials are thermally stable up to 300°C-350°C. At elevated temperature the chief aggregate characteristics which have great importance to

VOL. 7, NO. 7, JULY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

behavior of concrete include physical properties (e.g., thermal conductivity and thermal expansion), chemical properties (e.g., chemical stability at temperature), and thermal stability/integrity. However, thermal properties of concrete are influenced by the concrete's mixing proportions, aggregates thermo physical properties that it contains, and those of its hydrating cement (binder) paste component, (Bentz, D. P., 2007; Bentz, D. P. *et al.*, 2011). The temperature response analysis (Figure-1) of the structures can be subdivided into two major categories, a nonlinear temperature analysis and a successive structural analysis (Kang, S. W. *et al.*, 2001; Poh, K. W. *et al.*, 1995).

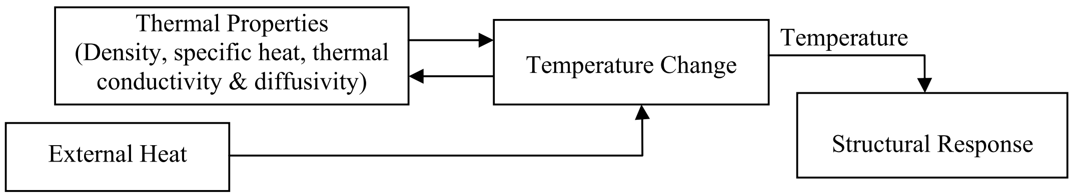

Figure-1. General procedure of thermal analysis.

Specific heat (C) measures the index of the capability with which concrete can undergo temperature changes. Concrete of high specific heat is beneficial for increasing the temperature stability of a structure. For this rationale measurement of specific heat of concrete is very essential. It is defined as the amount of heat that a unit mass of a material must gain or lose to change its temperature by a given amount. The specific heat of a material is correlated to heat capacity and is a property of the materials. In SI unit it would be expressed in term of Joules per kilogram per Kelvin (J/kg-K). For ordinary concrete the common range of values is between 840 and 1170 J/kg-K. It is greatly influenced by moisture content, types of aggregate used, and density of concrete (Neville, A. M. 1996; Phan, L. T., 1996; Kodur, V. R. *et al.*, 1998; Harmathy, T. Z., 1970).

Thermal diffusivity (δ) is a material property which defines the rate at which temperature changes within a mass can take place, through a material, and is thus an index of the facility with which concrete can undergo temperature changes, normally measured in m^2/h, m^2/s or ft^2/hr. In a sense, thermal diffusivity is the measure of thermal inertia (Venkanna, B. K., 2010). A substance having high thermal diffusivity, heat moves rapidly through because the substance conducts heat quickly compared to its volumetric heat capacity or 'thermal bulk'. The typical values of ordinary concrete ranges between 5.5×10^{-7} and 15.5×10^{-7} m^2/sec (0.02 to 0.06 ft^2/h), depending on the aggregate type used in concrete (Neville, A. M., 1996).

Thermal conductivity (K) is the capacity of the material to conduct heat and is defined as the ratio of the flux of heat to temperature gradient. Thermal conductivity is measured in joules per second per square meter of area of body while the temperature difference is 1°C or 1 K per meter of thickness of the body. The conductivity generally ranges between about 1.4 and 3.6 W/m-K (0.8 to 2.1 $Btu/ft^2h°F/ft$) (Scanlon, J. M. *et al.*, 1994) and varies with the density and permeability of concrete. It is the product of the thermal diffusivity, the specific heat, and the density. Hence, increasing all three parameters contribute to an increase in the thermal conductivity (Fu, X. *et al.*, 1999). Lower value of thermal conductivity concrete is beneficial for the thermal insulation of buildings. On the other hand, concrete of high thermal conductivity is advantageous for lessening temperature gradients in concrete structures. The thermal stresses that consequence from temperature gradients may cause mechanical property degradation and even twisting in the structure (Xu, Y. *et al.*, 2000).

Thermal conductivity, $K = C \rho \delta$ (1)

Where, c is the specific heat, ρ is the density and δ is the diffusivity of concrete.

In this study thermal properties (specific heat, thermal conductivity and diffusivity) of concrete using two different types of coarse aggregates were determined. And find out the acceptability of burnt clay brick-chips as aggregate in concrete industry.

MATERIALS AND METHOD

Materials

Portland composite cement (PCC) was used as binder. Various physical properties of the concrete ingredients are given in Tables 1 and 2. ASTM standards were followed to determine these properties. The maximum sizes of coarse aggregates for both types were kept 12.5 mm and maintain same gradation curve is shown in Figure-2 (ASTM, 2010; ASTM, 2006; ASTM, 2003).

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. Properties of cement.

Properties		ASTM standard requirement	Obtained value
Compressive strength (MPa)	**Age (Day)**	**(MPa)**	**(MPa)**
	3 days	≥ 12	18.3
	7 days	≥ 19	25.5
	28 days	≥ 28	28.8
Normal consistency (%)		--	27.8
Setting time (min)	Initial setting (min)	Not less than 45 min	126
	Final setting (min)	Not more than 375 min	250
Fineness (%)	Sieve No. 200 residue (%)	--	2.0

Table-2. Properties of aggregate (coarse and fine).

	Properties	Coarse aggregate types: Bricks chips	Coarse aggregate types: Stone chips
Coarse Aggregate	Maximum size (mm)	12.5 mm	12.5 mm
	Moisture content (%)	9.4	2.4
	Voids (%)	43.56	48.8
	Unit weight (kg/m^3)	898	1138
	Specific gravity	1.82	2.64
Fine Aggregate	Type	River bed sand	
	F.M. value	2.84	
	Specific gravity	2.70	
	Absorption capacity (%)	2.35	
	Unit weight (Kg/m^3)	1480	

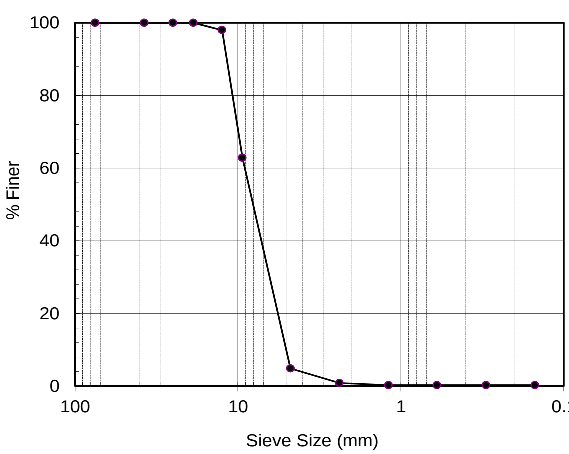

Figure-2. Gradation curve of coarse aggregate (brick-chips and stone-chips), performed according to ASTM C136 [13].

Sample preparation

Ninety six concrete cylinders of 4"× 8" in size were casted for these experiments. The concrete was mixed in proportions of 1:2:3 and 1:1.5:2 parts by volume of Portland composite cement (PCC), fine aggregate and coarse aggregates with water cement ratio 0.5. The variation of specific heat and thermal diffusivity of concrete were identified using two different types (burnt clay brick chips and stone chips) of coarse aggregates.
Sample identification:

B48R3

- R3: Proportion of Coarse Aggregate in Volume (1:2:3)
- 48: Specimen Size 4"× 8"
- B: Brick chips as Coarse Aggregate

For the expediency, the samples are identified with some ID marks. ID B48R3 means the concrete with mixing ratio 1:2:3 using brick chips as coarse aggregate; B48R2 means the concrete with mixing ratio 1:1.5:2 using brick chips as coarse aggregate; S48R3 means the concrete using stone chips with mixing ratio 1:2:3; S48R2 means the concrete using stone chips with mixing ratio 1:1.5:2.

Experimental procedures

Specific heat

The test specimens of 4"× 8" (100 mm × 200 mm) cylindrical shape were prepared and cured according to ASTM standard for 28 days. After curing two holes were made at the middle third point by drilling with a drill bid of 3/8" (9.5 mm) in diameter. Immersion heater (1000 watt and 220-250 volt) into one hole and a thermometer into another hole were inserted of the cylinders and put them into the calorimeter. Internal size of the semi adiabatic calorimeter (Figure-3) 9"×9"×18" was used in this experimental work.

VOL. 7, NO. 7, JULY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

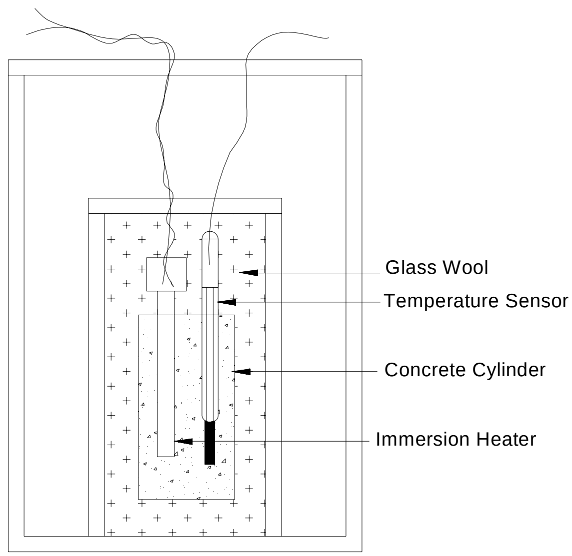

Figure-3. Semi-adiabatic calorimeter with a concrete sample.

The concrete sample with heater and thermometer was put in the calorimeter and the cables of temperature sensor and heater was drawn out through a hole which was made on the top of the calorimeter. The specific heat (C) of concrete was calculated using the following equation.

$$C = \frac{Q_2 - Q_1}{(m_2 - m_1)(\theta_1 - \theta_0)} \qquad (2)$$

Where, C = Specific heat, J/kg-K
θ_0 = Initial temperature
θ_1 = Final temperature
Q_1, Q_2 = Input energy of the samples
m_1, m_2 = mass of the samples

Thermal diffusivity

A thermocouple was inserted in an axially drilled hole 3/8 inch (9.5 mm) in diameter in the middle of the specimen. Top contact point of the thermocouple with the hole was sealed to prevent any leakage. Each specimen was immersed in a bath filled with boiling water (Figure-4) until the temperature of the concrete sample at its center reaches to the desired level. Then the specimen be transferred to a bath of cold water with constant temperature, and hanged up in the bath so that the specimen was entirely in contact with water.

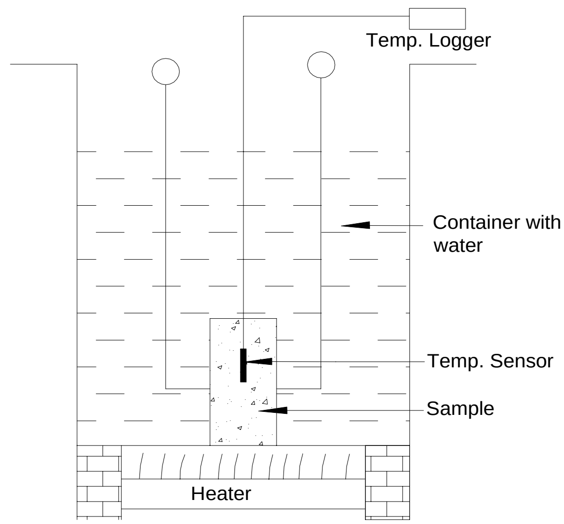

Figure-4. Specimen heating arrangement.

In the cooling bath (Figure-5), the temperature of the specimen was recorded at one minute interval from the time when the temperature difference between the center of the specimen and the water is 67°C until the temperature difference between the center and the water is 4°C.

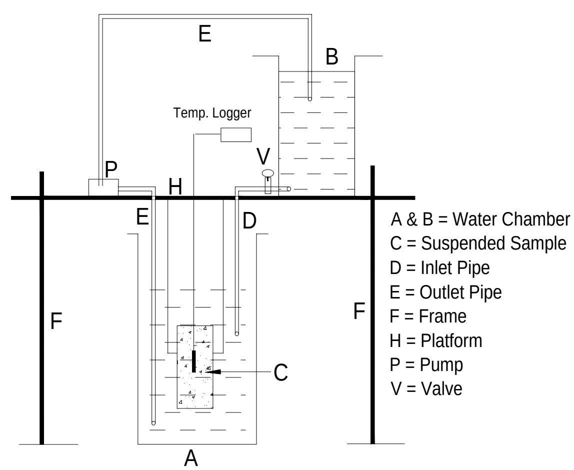

Figure-5. Cooling system of specimen.

The temperature difference in °C was plotted against the time in semi-logarithmic scale. A possible best fit curve was drawn. The time elapsed between the temperature of 44°C and 11°C was collected from the graph and used to find out thermal diffusivity (δ) using the following equation.

$$\delta = \frac{60 \ln\left(\frac{T_1}{T_2}\right)}{(t_2 - t_1)\left(\frac{5.783}{r^2} + \frac{\pi^2}{l^2}\right)} \qquad (2)$$

VOL. 7, NO. 7, JULY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Where, δ = Thermal diffusivity, m^2/sec
$(t_2 - t_1)$ = The time elapsed between the temperatures of 44°C and 11°C, min
T_1, T_2 = Temperature differences at time t_2 and t_1
r = Radius of cylinder, l = Length of cylinder

RESULTS AND DISCUSSIONS

The thermal properties of concrete cylinders of different categories were measured. The values of the measured properties are summarized in Table-3.

Table-3. Density, specific heat, thermal diffusivity and thermal conductivity of concrete.

Sample ID	Mix Proportion by volume	Density (kg/m^3)	Specific heat (J/kg-K)	Thermal diffusivity (m^2/sec) × 10^{-7}	Thermal conductivity (W/m-K)
B48R3	1:2:3	1970	1237	6.19	1.51
B48R3		2018	1227	5.68	1.41
B48R3		2066	1184	5.94	1.45
B48R3		1986	1258	5.94	1.48
B48R3		1922	1272	6.19	1.51
B48R3		2050	1225	6.19	1.56
S48R3		2146	1128	7.74	1.87
S48R3		2211	1110	8.00	1.96
S48R3		2243	1122	7.23	1.82
S48R3		2195	1153	8.26	2.09
S48R3		2259	1098	7.74	1.92
S48R3		2227	1109	8.00	1.98
B48R2	1:1.5:2	2002	1229	8.26	2.03
B48R2		2050	1218	9.03	2.26
B48R2		2050	1196	8.77	2.15
B48R2		2114	1178	8.52	2.12
B48R2		2034	1214	8.26	2.04
B48R2		2082	1224	8.52	2.17
S48R2		2339	1023	9.29	2.22
S48R2		2291	1080	9.55	2.36
S48R2		2307	1069	9.55	2.35
S48R2		2227	1088	9.29	2.25
S48R2		2291	1020	10.06	2.35
S48R2		2323	1018	9.81	2.32

In this table the density, specific heat, thermal diffusivity and thermal conductivity of different samples are categorized according to coarse aggregate types and mixing ratio. It is noted that the density of the concrete vary for different samples within each categories (for the same materials and same mixing ratio). Therefore, the values shown in the table are based on average densities ± a tolerance limit (less than 4%) in order to cover the range of densities as measured for different samples of the same category. The measured specific heat, and thermal diffusivity are presented based on the average values ± a variation (relatively small). The values of thermal conductivity of the samples are obtained by multiplying the density, thermal conductivity and diffusivity. The relationships of different thermal properties with each other are described in figures below.

Figure-6 presents the specific heat of concrete with brick-chips and stone-chips used as coarse aggregates. From this diagram it can be decided that the specific heat of concrete using the burnt clay brick-chips is greater than the concrete having stone-chips. The highest value of specific heat was measured 1258 J/kg-K and the lowest value is 1196 J/kg-K in case of brick-chips, but in case of stone-chips the value varies from 1153 to 1018 J/kg-K.

VOL. 7, NO. 7, JULY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

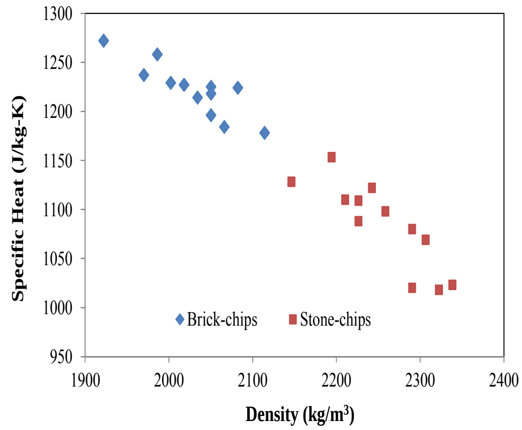

Figure-6. Specific heat of concrete.

Figure-7 shows the same values as in Figure-6. In this graph the values are characterized with respect to coarse aggregate types and mixing ratio.

It is observed that the B48R3 (brick-chips and 1:2:3 mixing ratio) type of concrete which have lower density shows greater specific heat and the higher density concrete S48R2 (stone-chips and 1:1.5:2) have lower specific heat. From these two Figures it can be concluded that the specific heat is inversely proportional to the density of concrete.

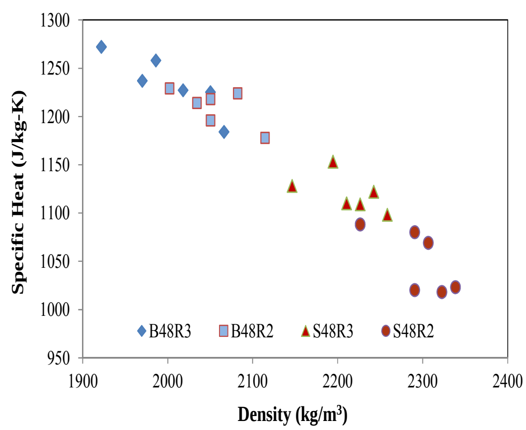

Figure-7. Specific heat of concrete with different mixing proportion.

Figure-8 illustrates data on thermal diffusivity of the tested samples having different categories. From the laboratory investigation it was observed that thermal diffusivity varies with the types of aggregate as well as the mixing ratios. It is shown that the thermal diffusivity of concrete specimen containing rich mixing proportion have greater value than the concrete containing lower mixing ratio. This is probably due to the variation in density of the concrete specimens. Rich mixing ratio gives higher density than the lower mixing ratio.

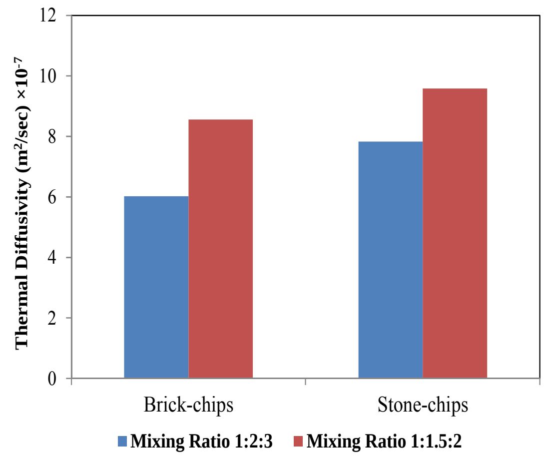

Figure-8. Thermal diffusivity of concrete with different mixing proportion.

Again in case of coarse aggregate types, the diffusivity of concrete is less when brick chips were used as coarse aggregate than the stone chips. In this laboratory investigation the brick chips used has lower unit weight than the stone chips. So the specimen made by using brick-chips showed lower density than the stone chips.

The relationship between thermal conductivity and thermal diffusivity of concrete for different categories of samples is presented in Figure- 9.

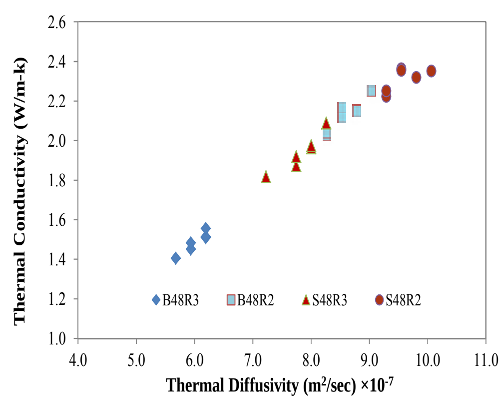

Figure-9. Relationship between thermal conductivity and diffusivity of concrete.

This figure shows a linear relationship between thermal conductivity and diffusivity as the thermal conductivity increases with the increasing amount of thermal diffusivity. Moreover, the values of thermal conductivity and diffusivity have a great affinity on the density of concrete. In both B48R3 and B48R2 specimen brick-chips were used as coarse aggregate but due to the difference of mixing proportion the density was varied. Specimens of B48R2 have greater thermal diffusivity and conductivity values than B48R3. The same trend is found in case of stone-chips.

CONCLUSIONS

From the experiment it can be concluded that the burnt clay brick-chips used as coarse aggregate shows greater specific heat than the stone-chips concrete. Mixing proportion also has influence on the specific heat and rich mixing proportions exhibits lower values when compared with lower mixing ratio.

Thermal diffusivity increases with increasing density. The diffusivity of concrete using stone-chips as coarse aggregate has greater values than concrete with brick-chips. Concrete samples with rich mix proportions exhibits higher diffusivity for both types of aggregates.

Thermal conductivity of both types of concrete is directly proportional to its diffusivity.

REFERENCES

ASTM. 2003. Standard Specification for Portland cement, ASTM C150 /C150M - 11, Annual Book of American Society for Testing Materials Standards. Vol. C 04.01.

ASTM. 2006. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM C136-06, Annual Book of American Society for Testing Materials Standards. Vol. C 04.02.

ASTM 2010. Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds, ASTM C873/C873M - 10a, Annual Book of American Society for Testing Materials Standards. Vol. C 04.02.

Bazant Z. P. 1982. Review of Literature on High-Temperature Behavior of Portland cement and Refractory Concretes, Normal and Refractory Concretes for LMFBR Applications. EPRI Report NP-2437, Northwestern University and Portland cement Association, Chicago, Illinois. Vol. 1.

Bentz D. P. 2007. Transient Plane Source Measurements of the Thermal Properties of Hydrating Cement Pastes. National Institute of Standards and Technology, USA.

Bentz D. P., Peltz M.A., Duran-Herrera A., Valdez P. and Juarez C.A. 2011. Thermal Properties of High Volume Fly Ash Mortars and Concretes. Journal of Building Physics. 34(3): 263-275.

DeSchutter G. 2001. Thermal Properties in Early Age Cracking in Cementitious Systems. Report 25, A. Bentur, RILEM Publications s.a.r.l.

Fletcher I. A., Welch S., Torero J. L. Carvel R. O. and Usmani A. 2007. Behaviour of Concrete Structures in Fire, Thermal Science. International Scientific Journal. 11(2): 37-52.

Fu X. and Chung D. D. L. 1999. Effect of Admixtures on Thermal and Thermo-mechanical Behavior of Cement Paste. ACI Mater J. 96(4): 455-461.

Harmathy T. Z. 1970. Thermal properties of concrete at elevated temperatures. J. Mater. pp. 47-74.

Kang S. W. and Hong S. G. 2001. Material Model and Thermal Response Analysis of Concrete at Elevated Temperatures. Journal of the Korea Concrete Institute. 13(3): 268-276.

Kodur V. R. and Sultan M. A. 1998. Structural behavior of high strength concrete columns exposed to fire. Proc., Int. Symp. on High Performance and Reactive Powder Concrete, Sherbrooke, Canada. pp. 217-232.

Mehta P.K. and Monteiro P.J.M. 2006. Concrete: Microstructure, Properties and Materials. The McGraw-Hill Companies, Inc., New York, USA.

Milovanovic B., Banjad P. I. and Gabrijel I. 2011. Measuring Thermal Properties of Hydrating Cement Pastes. 31st Cement and Concrete Science Conference, Novel Developments and Innovation in Cementitious Materials, Imperial College London, United Kingdom.

Naus D.J. 2005. Effect of Elevated Temperature on Concrete Materials and Structures- A Literature Review, U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research Under Interagency Agreement No. 1886-N674-1Y NRC FIN No. Y6741.

Neville A. M. 1996. Properties of Concrete. 4th Ed., ELBS, Addison Wesley Longman Ltd., Harlow, England, ISBN 0582 279380.

Phan L. T. 1996. Fire Performance of High-Strength Concrete. A Report of the State-of-the-Art. Rep. NISTIR 5934. National Institute of Standards and Technology, Gaithersburg, MD.

Poh K. W. and Bennetts I. D. 1995. Analysis of Structural Members under Elevated Temperature Conditions. Journal of Structural Engineering. 121(4): 664-675.

Portland Cement Association. 2003. Design and Control of Concrete Admixtures. 14th ed.-CD Version, CD100.1.

Scanlon J. M. and McDonald J. E. 1994. Thermal Properties in Concrete and Concrete Making. ASTM Sp. Tech. Publ. No. 169C, Philadelphia, Pa. pp. 299-339.

ARPN Journal of Engineering and Applied Sciences

Schindler A.K. and McCullough B. F. 2002. The Importance of Concrete Temperature Control during Concrete Pavement Construction in Hot Weather Conditions. A paper offered for publication at the Annual Meeting of the Transportation Research Board., Washington, D.C, USA.

Schneider U., Diererichs C. and Ehm, C. 1981. Effect of Temperature on Steel and Concrete for PCRV's. Nuclear Engineering and Design. 67: 245-258.

Venkanna B.K. 2010. Fundamentals of Heat and Mass Transfer, New Delhi: PHI Learning. ISBN 978-81-203-4031-2. pp. 38. Retrieved 1 December 2011.

Whittier S., Olyniec J. and Mcglohn R. 2004. Minimizing Temperature Differentials in Mass Concrete, Concrete International. pp. 42-45.

Xu Y., and Chung, D.D.L. 2000. Cement of High Specific Heat and High Thermal Conductivity, Obtained by Using Silane and Silica Fume as Admixtures. Cement and Concrete Research. Elsevier Science Ltd. pp. 1175 -1178.

Zhuze V. P., Novruzov O. N. and Shelykh A. I. 1969. Thermal Conductivity near a Continuous Phase Transition, Soviet Physics-Solid State (English translation, American Institute of Physics, New York, USA). 11: 1044.