Thermal Properties of Recycle Aggregate Concrete with Different Densities

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ABSTRACT

The present research intended to determine thermal properties (thermal conductivity, thermal diffusivity and specific heat) of concrete manufactured by recycle waste of clay brick and thermostone for using it as aggregate after crushing process. For this purpose, three concrete mixes were prepared one of them using crushed clay brick as aggregate and two others were used crushed thermostone as aggregate too, these three mixes compared with reference normal concrete mix. Specific heat was measured by using semi-adiabatic calorimeter method whereas thermal diffusivity was measured by using heating-cooling system. Thermal conductivity was obtained by multiplying the thermal diffusivity, specific heat and density. From experimental laboratory work, it was concluded that the thermal diffusivity increase with concrete density increment, but the specific heat was decreased with concrete density increment. Thermal conductivity had a linear relationship with thermal diffusivity. Mixing ratio also had an influence on thermal properties of concrete.

Keywords: Recycle aggregate, specific heat, compressive strength, thermal diffusivity, absorption.

الخواص الحرارية للخرسانة ذات الركام المعاد تدويره بمختلف الكثافات

الخلاصة

البحث الحالي يهدف الى تحديد الخواص الحرارية (معامل التوصيل الحراري, الأنتشارية الحرارية و الحرارة النوعية) لخرسانة مصنعة من المخلفات المعاد تدويرها من الطابوق والثرمستون لأستعماله كركام بعد عمليات التكسير. ولهذا الغرض تم تحضير اربع خلطات خرسانية واحده منها بأستعمال مكسر الطابوق كركام والأثنان الاخرى بأستعمال مكسر الثرمستون كركام أيضا, وهذه الثلاث خلطات تقارن مع خلطة خرسانية عادية مرجعية. الحرارة النوعي تم قياسها بواسطة طريقة المسعر شبه الثابت للحرارة بينما الأنتشارية الحرارية تم قياسها بطريقة نضام التسخين والتبريد. معامل التوصيل الحراري تم الحصول عليه بواسطة حاصل ضرب الأنتشارية الحرارية, الحرارة النوعية و الكثافة. من العمل المختبري أستنتج بأن الأنتشارية الحرارية تزداد بزيادة كثافة الخرسانة لكن الحرارة النوعية تقل بزيادة كثافة الخرسانة. معامل التوصيل الحراري يملك علاقة خطية طردية مع الأنتشارية الحرارية. نسب الخلط ايضا لها تأثير على الخواص الحرارية للخرسانة.

INTRODUCTION

Concrete in many types and forms has been used extensively in all manner of constructions for many years mainly because of its reasonable properties and versatility to shape and ease of production. The increasing awareness of energy conservation and heat transfer control coupled with the introduction of basic standards of the performance and the continued increase in the use of concretes in civil engineering applications such as construction of buildings, roads, dams, mass concretes, storage tanks etc. has focused more attention on the evaluation of its thermal properties.

One of the main challenges in the concrete structures design is to avoid the initiation of cracks regardless of the concrete element size, procedure of concreting, weather conditions and material properties used [1]. The analysis of temperature and stress due to the hydration of concrete is a 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. Due to global warming, temperature increases quickly. As a result of urbanization, a huge amount of carbon dioxide (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.

The aggregates typically account for 70-80% of concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability [2],

Specific heat is the amount of heat that a unit mass of a material must gain or lose to change its temperature by a given amount.. 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. 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 [3].

Thermal diffusivity 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. The typical values of ordinary concrete ranges between ($5.5\times10^{-7}$and $15.5\times10^{-7}\times m^2/sec$) depending on the aggregate type used in concrete[4,5]

Thermal conductivity is the capacity of the material to conduct heat also defined as the ratio of the flux of heat to temperature gradient. Thermal conductivity is measured in (watt/m.k). The thermal conductivity value of normal concrete ranges from 0.62 to 3.3 W/m/K across more than five folds of magnitude depending on the types of coarse aggregate, moisture condition and temperature[6] . The reported values in lightweight concrete also reside between 0.4 and 1.89 W/m/K . The lightweight insulating concrete with polystyrene bead or cellular lightweight concrete even exhibits the thermal conductivity of 0.07–0.33 W/m/K [5,6,7].

Conventional concrete consists of sand as fine aggregate and gravel in various sizes and shapes as a coarse aggregate. There is a growing interest in using waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitutes such as rubber waste, fiber glass waste materials, waste plastics, waste clay brick, waste thermostone and others. The consumption of waste materials can be increased manifold if these are used as aggregate into cement mortar and concrete. This type of a waste material can solve problems of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of waste aggregate can also reduce the cost of concrete production. As the aggregate can significantly control the properties of concrete, the properties of the aggregate have a great importance. Mohammed et al[8] present several concrete mixes using lightweight aggregate (crushed thermostone and porcellanite &suwdast) to obtain lightweight concrete of two densities ranging from (350-880 kg/m3), which provides a good thermal insulation.

Experimental Program

Materials

Cement

Ordinary Portland cement (type I) manufactured in Iraq with the trade mark of (Tassloga) has been used throughout this investigation. Its chemical composition and physical properties were found to satisfy the limits of the Iraqi specification No.5/1984[9].

Coarse Aggregate

Three type of coarse aggregate are used throughout this investigation they are**:-**

- Natural gravel

A crushed coarse aggregate brought from (Al-Soddor source), has been used throughout the work .Its max size was (10 mm) ,the grading of crushed coarse aggregate was as shown in Table (3.3) . It conforms to the Iraqi specification No.(45)-1984 [10] .The specific gravity , bulk density ,absorption, and the sulfate content of the crashed coarse aggregate were 2.68,1565,0.6%,0.05% respectively.

- Crushed clay-brick aggregate

The clay bricks one of the materials used widely in construction work in Iraq. A waste crushed clay brick was used as coarse aggregate. To produce it, the following procedure was depended on:-

1. The waste broken bricks were crushed into smaller sizes manually by using a hammer to obtain the required sizes (10 mm maximum size) .
2. The crushed clay brick was sieved in the standard sieve as shown in Table (3-4) according to ASTM C330_03[11] ,the specific gravity, bulk density and absorption were (2.16, 1125, 21%) respectively.
3. The crushed clay brick aggregate was washed in water to remove dust then submerged in water for 24 Hrs
3. Finally, the crushed clay brick aggregate was spread inside the laboratory and was exposed to air for a suitable time to have a saturated surface dry (S.S.D) condition.

- Crushed thermostone aggregate

The crushed thermostone aggregate was used as fine and coarse aggregate, and the required quantity of crushed thermostone was brought from different locations. After that the large pieces were crushed into smaller sizes manually by means of hammer in order to reach the desired gradation with maximum size of 10 mm. the crushed thermostone was sieved in standard sieve as shown in Table (3-5) according to ASTM C330_03[11] , the specific gravity, bulk density and absorption were (1.14, 560, 53.6%) respectively.

Notably that all amounts of crushed thermostone user was washed with water before using it to get rid of dust because it cause segregation. It was then submerged in water for(24) Hrs then the crushed thermostone was spared inside the laboratory for an appropriate period (about 6 hours) to reach the status of "saturated surface dry.

Fine Aggregate-

Natural sand has been used from (Al-Soddor source), as a fine aggregate after it has been sieved by sieve size (4.75 mm).The grading of fine aggregate was as shown in Table (3.6).It was conformed to Iraq specification No.(45)-1984 [10] where the gradation lies in zone (3) . The specific gravity, bulk density and absorption of the fine aggregate were (2.65, 1650, 2.2%).

Water

Potable water was used throughout this investigation for washing, mixing and curing.

Mixes , Mixing and Preparation of Specimen

After conducted many trial mixes to select the suitable mix, the final mix had the following constituents for each type of aggregate used:-

1.C_N (1/6.4) cement/aggregate ratio by volume with w/c ratio= 0.45 (3.6 natural coarse aggregate and 2.8sand)

2.C_B (1/2.2)) cement/aggregate ratio by volume with w/c ratio= 0.55 (all in crushed clay brick aggregate)

3.$C_{TH-1500}$ (1/3.75)) cement/aggregate ratio by volume with w/c ratio= 0.57 (all in crushed thermostone aggregate).

4.$C_{TH-1400}$ (1/4.6)) cement/aggregate ratio by volume with w/c ratio= 0.6 (all in crushed thermostone aggregate).

A 100 mm cubes, (100*200) mm cylinders steel moulds have been used to prepare the test specimen of this study.

After preparation materials volumetric method followed because crushed clay brick and thermostone considered as lightweight aggregates. . The first mixture was used normal coarse and fine aggregate as reference with expected density of about (2000_2400) kg/m3.The other mixtures were prepared in order to have different densities. In this investigation, the main objective has been conducted to determine thermal properties (thermal conductivity, thermal diffusivity and specific heat) for recycle concrete with different densities.

Experimental Tests

Compressive Strength Test

The compressive strength was determined from cubes of (100*100) mm specimen's according to B.S.1881[12] .

Water Absorption•

The water absorption test was carried out according to ASTM C642[13].

Oven dry density•

The oven dry density was conducted in accordance ASTM-C567 [14]. on (100*100) mm cubes. The specimens were cured until the age of testing. After that, the specimen were dried in ventilated oven 105±5 °C until constant mass is achieved. Then the specimen was cool near room temperature. The density is calculated as follows:

$$Ᵽ = m / v \qquad ...(1)$$

Where:-

Ᵽ: oven dry density (kg/m^3).

m: mass of oven dry specimen (kg).

v: volume of oven dry specimen (m^3).

Heating-cooling system method to measuring thermal diffusivity of concrete. • testing procedure

1. A thermocouple was inserted in an axially drilled hole (9.5 mm) in diameter in the middle of the test specimen(cylinder 100*200 mm).
2. Top contact point of the thermocouple with the hole was sealed to prevent any leakage.
3. test specimen was immersed in a bath filled with boiling water until the temperature of the concrete sample at its center reaches to the desired level see Fig. (1).
4. Then the specimen be transferred to a bath of cold water with constant temperature, the specimen should be entirely in contact with water see Fig (1).
5. In the cooling bath, 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.
6. 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.

$$\delta = \frac{\ln(\frac{T1}{T2})}{60(t2-t2)(\frac{5.783}{r^2}+\frac{\pi^2}{l^2})} \qquad .....(2)$$

Where:-

δ = Thermal diffusivity, m^2/sec.

(t2 - t1) = The time elapsed between the temperatures of 44°C and 11°C, min.

T1, T2 = Temperature differences at time t2 and t1.

r = Radius of cylinder, m

l = Length of cylinder, m

Figure (1). Heating Cooling system for measuring thermal diffusivity.

Semi-adiabatic calorimeter method to measuring specific heat of concrete. • testing procedure

1. The test specimen of (100 mm × 200 mm) cylindrical shape were prepared and cured for 28 days.
2. Two holes were made at the middle third point by drilling with a drill bid of (9.5 mm) in diameter.
3. Immersed heater (800 watt 110_120 volt) into one hole and a thermometer into another hole and put them into the semi-adiabatic calorimeter as shown in Fig (2).
4. The concrete sample with heater and thermometer was put in the calorimeter and the cables of temperature sensor and heater were 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.

$$C = \frac{Q}{(m)*(\theta 1-\theta 2)} \qquad \text{.......(3)}$$

Where:-
C = Specific heat, J/kg-K.
$\theta 0$ = Initial temperature, K.
$\theta 1$ = Final temperature, K.
Q1 = Input energy of the samples, J.
m = mass of the samples, kg.

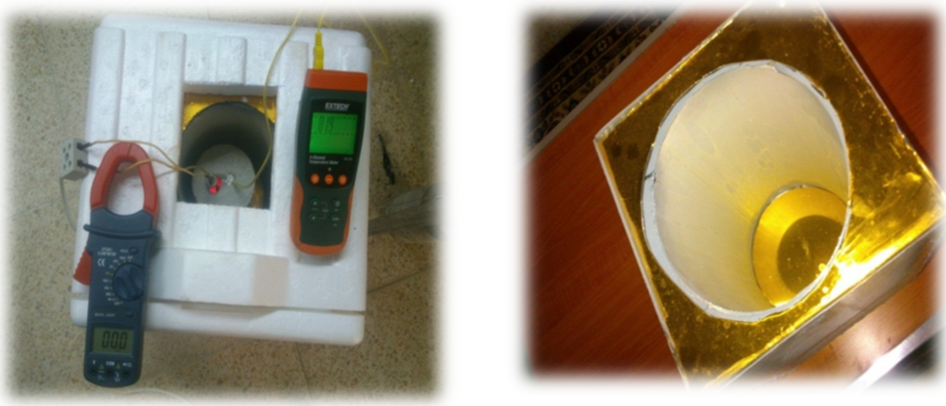

Figure (2): Semi-adiabatic calorimeter apparatus.

Result and Discussion

The mechanical and thermal properties of concrete with different types of aggregate are summarized in Table_1.

Table (1) mechanical and thermal properties of studied concrete mixes.

Type of mix	Mix proportion By volume	Compressive Strength (MPa)	Absorption (%)	Oven dry density Kg/m^3	Thermal diffusivity (m2/sec) × 10^{-7}	Specific heat (J/kg-K)	Thermal conductivity w/m.k
C_N	1/6.4	25	6.5	2153	6.9	890	1.3
C_B	1/2.2	25	23	1596	3.6	1357	0.77
$C_{TH-1500}$	1/3.75	13.6	22	1265	4.5	1676	0.95
$C_{TH-1400}$	1/4.6	10.8	35	1070	3.2	2098	0.7

In this Table compressive strength, absorption, oven dry density, thermal diffusivity, specific heat and thermal conductivity of different samples according to aggregate types and mixing ratio.

Specific heat

It is noted from Table 1 that density of concrete vary for different samples, this is because pores natural of crushed clay brick and thermostone aggregate compared with natural aggregate. Fig. 3 presents the relationship between density and specific heat of concrete mixes, from this Figure it can be decided that the specific heat of normal concrete mix lower than specific heat for crushed clay brick and thermostone and whenever concrete density decrease specific heat increase because amount of heat that a unit mass of concrete sample gain to change its temperature increase due to pores and light weight of sample itself, from it can be concluded that the specific heat is inversely proportional to the density of concrete.

Thermal diffusivity

The typical values of ordinary concrete range between (5.5×10-7and 15.5×10-7×m²/sec) depending on the aggregate type used in concrete. Fig. 4 shows the result of thermal diffusivity for studied concrete mixes. The reference concrete mix which is normal concrete mix the value of thermal diffusivity is (6.9×10-7 m²/sec). This is within the limit. When using crushed clay brick as a lightweight aggregate to produce concrete with density less than normal concrete the value of thermal diffusivity decrease to (3.6×10-7 m²/sec) for all in clay brick concrete, but for $C_{TH-1500}$ concrete mix although has lower density than C_B diffusivity higher than it this is because porous natural of this type of aggregate which makes the heat moves faster than in the case of using crushed clay brick. Fig. 6 illustrate that the specific heat is inversely proportional to the thermal diffusivity of concrete because "Diffusivity is a measure of how quickly a body can change its temperature", i.e., how quickly heat can travel (diffuse) into the body. Obviously, higher thermal conductivity allows quicker propagation of heat into the body (diffusivity is directly proportional to thermal conductivity). Higher density and specific heat mean that heat arriving at a layer is stored rather than transmitted to the next layer. Hence, it is an inverse relationship between diffusivity and the specific heat.

Thermal conductivity

The thermal conductivity was obtained by multiplying the specific heat, density and thermal diffusivity. The relationship between thermal conductivity and thermal diffusivity of concrete for different categories of samples is presented in Fig. 5. This figure shows a linear relationship between thermal conductivity and diffusivity as the thermal conductivity increases with the increasing amount of thermal diffusivity This result was in agreement with Milon[5]. Moreover, the values of thermal conductivity and diffusivity have a great similarity on the density of concrete.

Compressive strength

In the most concrete types, the aggregate phase is the most powerful (in term of strength) from the other phases, In light weight cellular aggregate case the size and shape of aggregate were have strong effect in concrete strength consequently weaker particles require stronger mortars and thus higher cement contents. Studied concrete mix demonstrate compressive strength for crushed clay brick similar to reference concrete mix due to higher cement content, the purpose of using lower aggregate ratio for crushed clay brick concrete mix is to reducing density, but for crushed thermostone concrete the compressive strength decrease with increase aggregate /cement ratio this is because weaker particles of crushed thermostone and due to decrease dry density of concrete.

Absorption

The results indicate that the concrete specimens for crushed clay brick and thermostone exhibited increment in absorption values when compared with their corresponding normal aggregate concrete because absorbability of normal aggregate lower than their corresponding crushed clay brick and thermostone aggregate, where the type of aggregate used had the direct effect on the total absorption value of concrete.

Conclusions

Based on the results and discussions, the following conclusions can be drawn:

1) It is possible to produce aggregate from crush waste of clay brick and thermostone to be used in light weight concrete productions.

2) The water absorption of crushed clay brick and thermostone aggregate mixes is higher than the water absorption of natural aggregate mixes.

3) Increment of cement/aggregate ratio for thermostone concrete mix leads to increase absorption, decrease compressive strength and density.

4) Thermal conductivity of concrete is directly proportional to its diffusivity.

5) Specific heat of concrete decrease with increasing density of concrete, but thermal diffusivity of concrete increase with increasing density.

Table (2) Physical properties of cement (Type I) .

Physical properties	Test results	Limit of Iraq specification No.(5) _ 1984[9]
Specific surface area (Blaine method), m^2/kg	483	≥230
Setting time (Vicate apparatus), Initial setting time, hrs: min Final setting time, hrs: min	2.50 4.30	≥45 min. ≤ 10 hrs
Soundness (Auto Clave) method, %	0.25	≤0.8

Table (3) Chemical oxide analysis, weight %, for cement used.

Oxide	Content %	Limit of Iraq specification No.(5) _ 1984[9]
CaO	52.21	__
SiO_2	20.18	__
Al_2O_3	5.00	—
Fe_2O_3	3.60	__
MgO	2.31	<5
SO_3	1.44	< 2.8
Na2O	0.28	__
K_2O	0.51	__
Insoluble Residue I.R	1.11	<1.5
Loss on ignition L.O.I	3.29	<4.0
Lime Saturation Factor ,L.S.F.	0.94	0.66-1.02

Table (4) The grading natural of coarse aggregate

Sieve size (mm)	% passing	Limit of Iraq specification No.(45) _ 1984[10]
12.5	100	100
10	86	100-85
4.75	8	25-0
2.36	0	5-0

Table (5) The grading of crushed clay brick

Sieve size (mm)	% passing	Limit of ASTM C330_03[11]
12.5	100	95-100
9.5	98	---
4.75	51	50-80
2.36	14.5	---
1.18	4.5	---
0.3	7	5–20
0.15	4	2–15
0.75	2	0–10

Table (6) The grading of crushed thermostone.

Sieve size (mm)	% passing	Limit of ASTM C330_03[11]
12.5	100	95-100
9.5	97	---
4.75	53	50-80
2.36	14	---
1.18	6.7	---
0.3	5	5–20
0.150	3.5	2–15
0.75	2	0–10

Table (7) :Grading & soluble material for fine aggregate .

Sieve size (mm)	% Passing Sand	Limits of Iraqi specification No.45/1984[10] (Cumulative passing % zone 3)
9.5	100	100
4.75	92.0	90-100
2.36	82.8	85-100
1.18	76.1	75-100
0.6	63.4	60-79
0.3	35.9	12-40
0.15	9.8	0-10
Fine Material%	4.6%	≤5%
Organic Material%	0.69%	≤3%

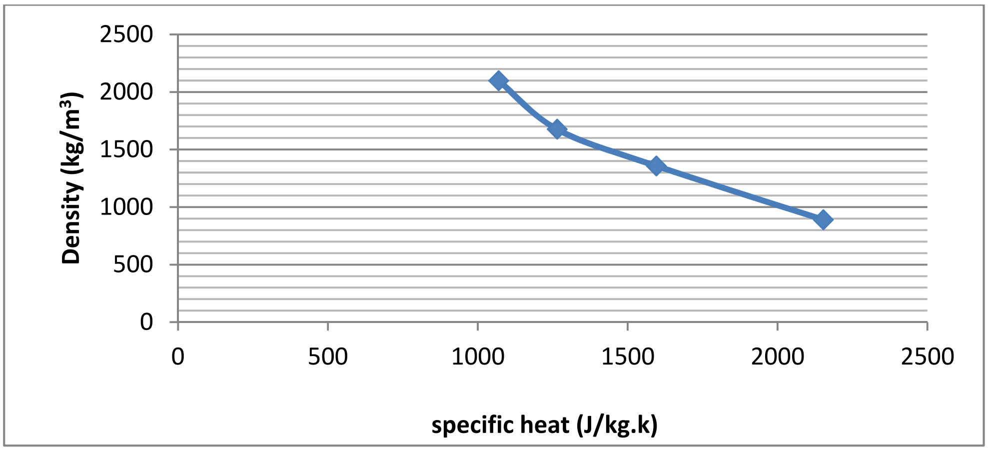

Figure.(3)relationship between density and specific heat

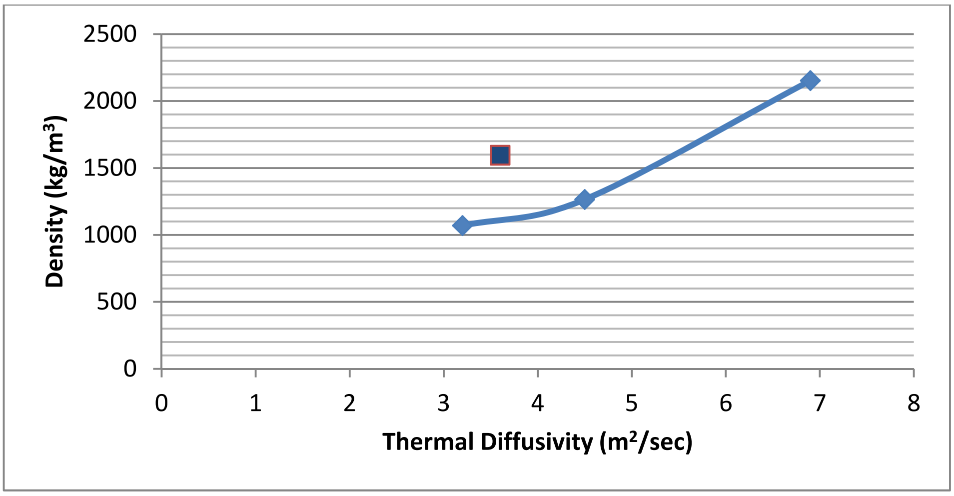

Figure.(4) Relationship between density and thermal diffusivity

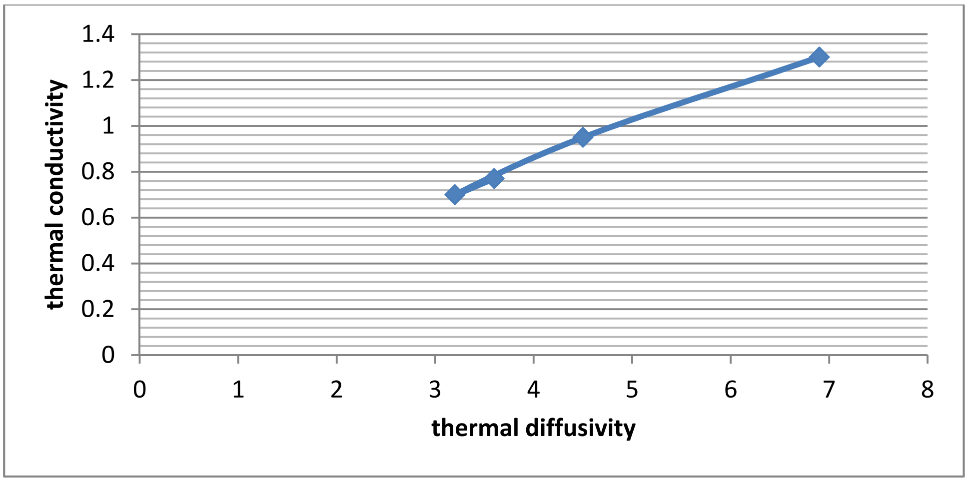

Figure.(5) relationship between thermal conductivity and thermal diffusivity.

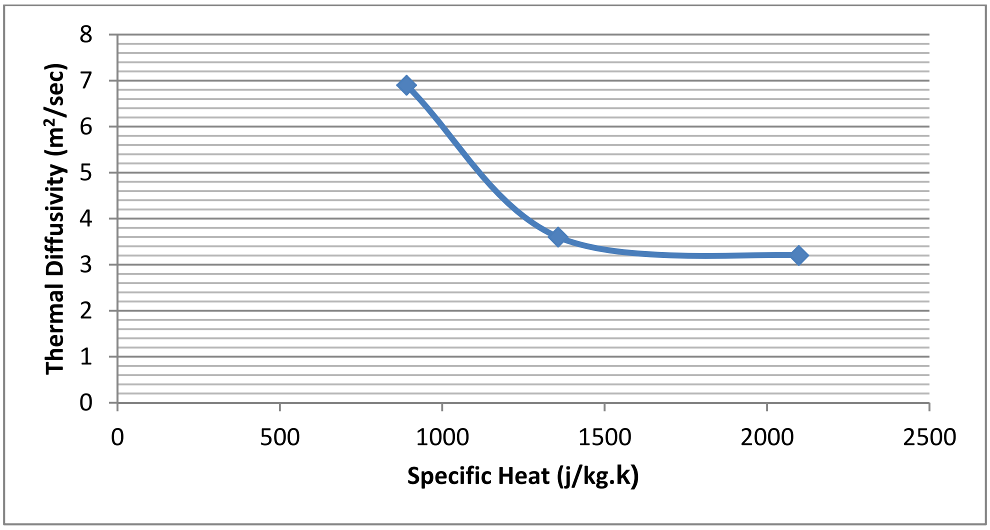

Figure.(6) relationship between thermal diffusivity and specific heat

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