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An Experimental Study on Age Effect under Saturated Condition on Thermal Properties of Mass Concrete

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Abstract: This paper presents experimental study, investigating the effect of age on thermal properties of mass concrete. Six design mixes were analysed for thermal properties i.e. Thermal Conductivity, Diffusivity and Specific Heat using Hot Disk TPS 1500 system at the age of 7, 28, 56 and 90 days and tests were performed on samples of the same volume (150 x 150 x 150 mm) under saturated curing conditions and at room temperature. It is expected that the thermal properties of the concrete depends on its age and the applied curing conditions. The thermal properties of concrete can progress with the progression of hydration. While the hydration process is highly dependent on the curing condition that is applied. Results also show increase in thermal conductivity and diffusivity of concrete with age under saturated condition whereas specific heat decreases.

Keywords: Thermal Properties, Thermal Conductivity, Diffusivity, Specific Heat, Mass Concrete, Hot Disk TPS 1500

I. INTRODUCTION

The thermal properties like Thermal Conductivity, Diffusivity and Specific Heat are important for evaluation of performance of concrete over a period of time. Concrete has relatively high thermal mass, allowing it to absorb and store significant amounts of heat. However, its thermal conductivity is moderate, influencing its ability to transfer heat. These properties contribute to the material's role in moderating temperature fluctuations within structures. The thermal properties of concrete are subject to various factors such as cement types & its content, aggregate types & content, air content, water, chemical and mineral admixture, age of concrete, saturation, temperature etc. and may change with variation in these factors. The thermal conductivity and diffusivity at later age in saturated condition has higher value as compared to earlier age while specific heat behaves in the opposite manner. This paper presents an experimental study carried out to measure the thermal properties of mass concrete. The study aims to understand how age affects thermal conductivity of concrete under saturated conditions.

II. LITERATURE REVIEW

The thermal characteristics that affect the increase and distribution of temperature within a concrete structural element include thermal conductivity, specific heat, and thermal diffusivity, which are defined as follows:

A. *Thermal Properties of Concrete*

The thermal properties of concrete are coefficient of expansion, conductivity, specific heat, and diffusivity. The relationship of diffusivity, conductivity, and specific heat is defined by

$$h^2 = \frac{K}{C\rho}$$

h^2 = Thermal diffusivity (m^2/h);
K = Thermal conductivity, (J/m·h·°C);
C = Specific heat, (J/kg·°C); and
ρ = Density of the concrete (kg/m^3),

1) *Thermal Diffusivity (h^2)*

Diffusivity represents the rate at which temperature changes within a mass can take place, and is thus an index of the facility with which concrete can undergo temperature changes. The range of typical values of diffusivity of ordinary concrete is between 0.002 and 0.006 m^2/h, depending on the type of aggregate used. The following rock types are listed in order of increasing diffusivity: basalt, limestone, and quartzite.

2) *Thermal Conductivity (K)*

It is the rate of heat flow per unit area under a unit temperature difference between the two faces of material of unit length. In general terms, basalt and trachyte have a low conductivity, dolomite and limestone are in the middle range, and quartz exhibits the highest conductivity.

3) *Specific Heat (C)*

It is the amount of heat required to raise the temperature of unit mass of concrete by one degree Celsius. Specific heat increases with an increase in temperature and with a decrease in the density of the concrete. The common range of values for ordinary concrete is between 850 and 1050 J/kg per °C.

III. PRESENT STUDY

The scope of laboratory studies of mass concrete involves: three mass concrete mix design of M15A80 grade with PPC, one mix design of M15A80 grade concrete with PSC, one of M15A150 grade concrete with PPC and one of M15A150 grade concrete with PSC (Table 1).

Table 1: Concrete Mix Proportion

Mix	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Mix Type	M15A80	M15A80	M15A80	M15A150	M15A80	M15A150
Type of Cement	PPC	PPC	PPC	PPC	PSC	PSC
Cement content (kg/m^3)	210	210	200	170	212	215
Coarse Aggregate (kg/m^3)						
150-80 mm	-	-	-	584.70	-	420
80-40 mm	518.14	518.14	540.92	416.68	559	390
40-20 mm	409.62	409.62	444.01	331.31	479	320
20-10 mm	309.66	309.66	357.91	168.64	400	270
10-4.75 mm	235	235	146.49	168.02	160	225
Fine Aggregate (kg/m^3)	591.58	591.58	570.76	535.07	513	490
Water (Kg/m^3)	115.5	115.5	110	86.70	110	107
Admixture (kg/m^3)	0.84	0.84	1.4	1.020	1.48	1.4
AEA (kg/m^3)	0	0	0.20	0.17	0.21	0.21

A. *Determination of Thermal Properties of Mass concrete*

For evaluating the thermal properties of mass concrete, three cubes of 15x15x15 cm of each design mix after wet sieving were casted as per Table 1. For the water curing and SSD conditions, the cylindrical concrete specimens were demoulded after 24 hours of pouring concrete into moulds and then cured in water storage at a temperature of 27 ± 2°C. The cubes were then cut in two equal halves with concrete cutting machine in the laboratory as shown in Figure 4. The samples were then placed in the water at a temperature of 27 ± 2°C. Before conducting the tests, the moisture on the surfaces of the cubical concrete specimens was removed with towels. Following this, the specimens were kept at room temperature in the laboratory until the measurements were taken. The tests were carried out with ~~a~~ Hot Disk TPS 1500. Thermal properties observed at 7, 28, 56 and 90 days.

Fig. 4: Cutting of cubes

Fig. 5: Hot Disk TPS 1500

1) Working Principle of Hot Disk TPS 1500

The Hot Disk TPS 2500 S system works on Transient Plane Source technique which employs two samples halves, in-between which the sensor is sandwiched as shown in Figure 6.

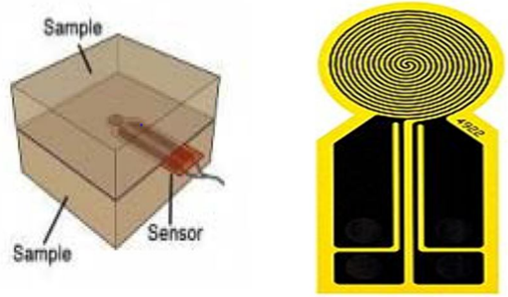

Fig. 6: Placing of sensor between two halves of sample halves and sensor

The flat sensor consists of a continuous double spiral of electrically conducting nickel (Ni) metal, etched out of a thin foil. The nickel spiral is situated between two layers of thin polyimide film Kapton. The thin Kapton films provide electrical insulation and mechanical stability to the sensor. The sensor is placed between two halves of the sample to be measured. During the measurement a constant electrical effect passes through the conducting spiral, increasing the sensor temperature. The heat generated dissipates into the sample on both sides of the sensor, at a rate depending on the thermal transport properties of the material. By recording temperature vs. time response in the sensor, the thermal conductivity, thermal diffusivity and specific heat capacity of the material can be calculated.

2) Measurements and Results

A sensor of radius approximately 14.61 mm is placed between two halves as shown in Figure 7 of the samples and given a power as per Table 2.

Fig. 7: Placing of sensor between two halves of sample and recording of measurements

Table 2: Power given and duration

Mix	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Mix Type	M15A80	M15A80	M15A80	M15A150	M15A80	M15A150
Power in mW	850	850	650	650	1000	1000
Time in s	80	80	80	80	80	80

The software measured and recorded the data automatically and plotted the graphs as shown in Figure 7.

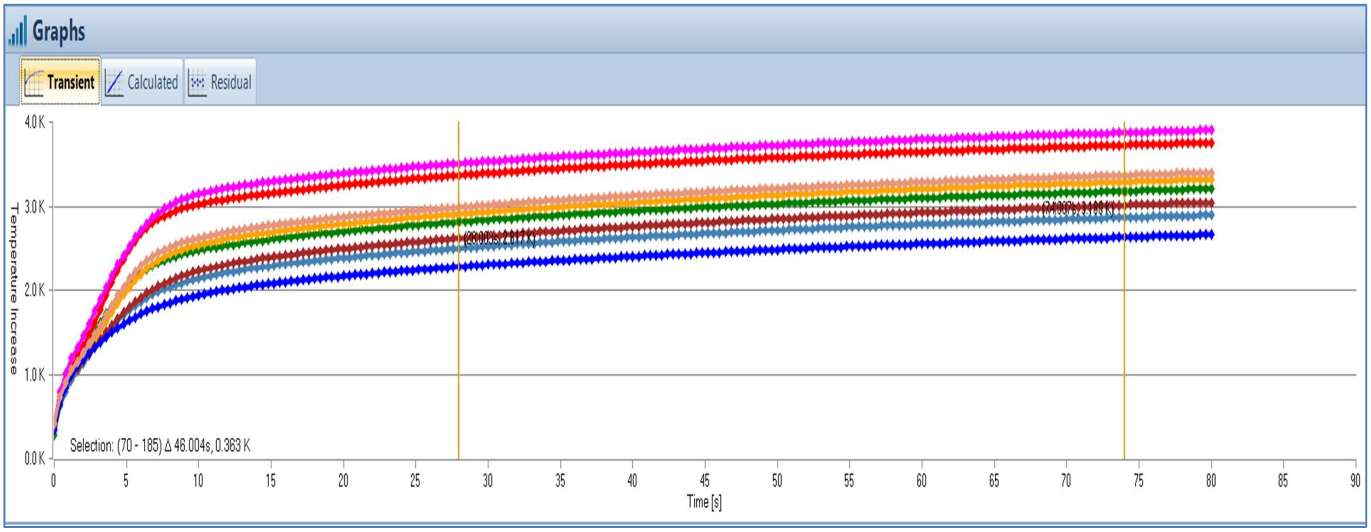

Fig.7: Graphs plotted by software

The value of thermal conductivity, specific heat, and thermal diffusivity for each Mix was calculated by averaging the three samples of cube at an age of 7, 28, 56 and 90 days and is shown in figure 8, 9 and 10.

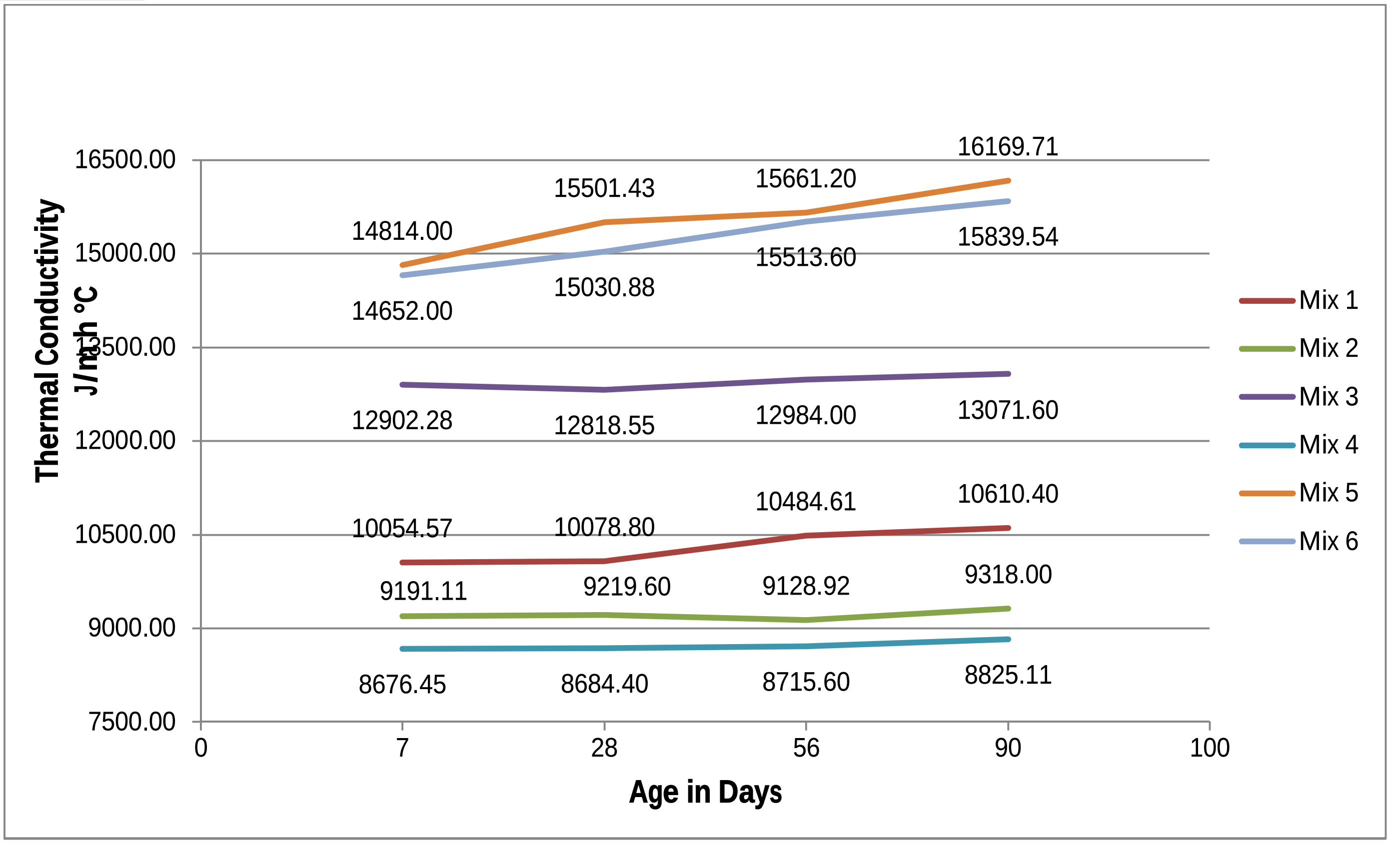

Fig. 8: Thermal Conductivity at 7, 28, 56 and 90 days

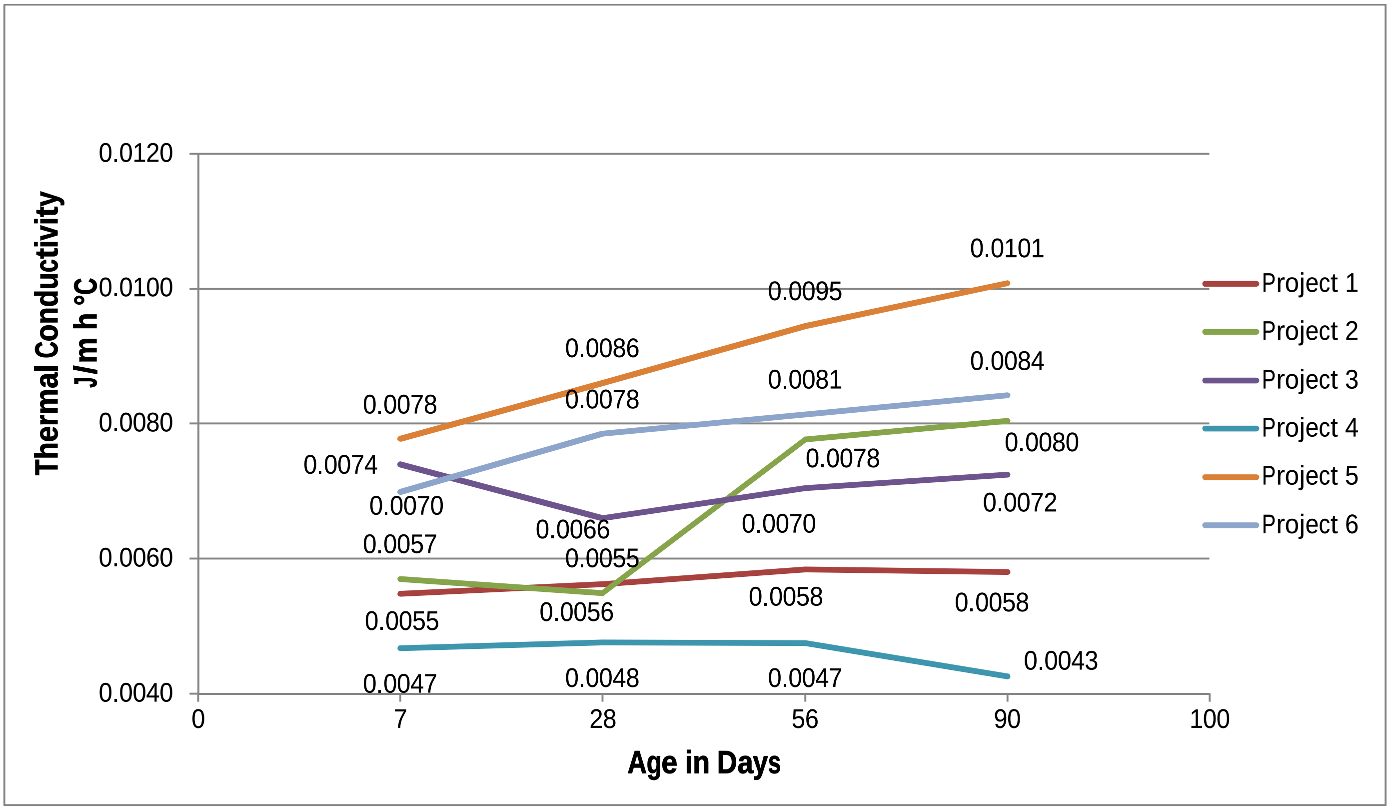

Fig. 9: Thermal Diffusivity at 7, 28, 56 and 90 days

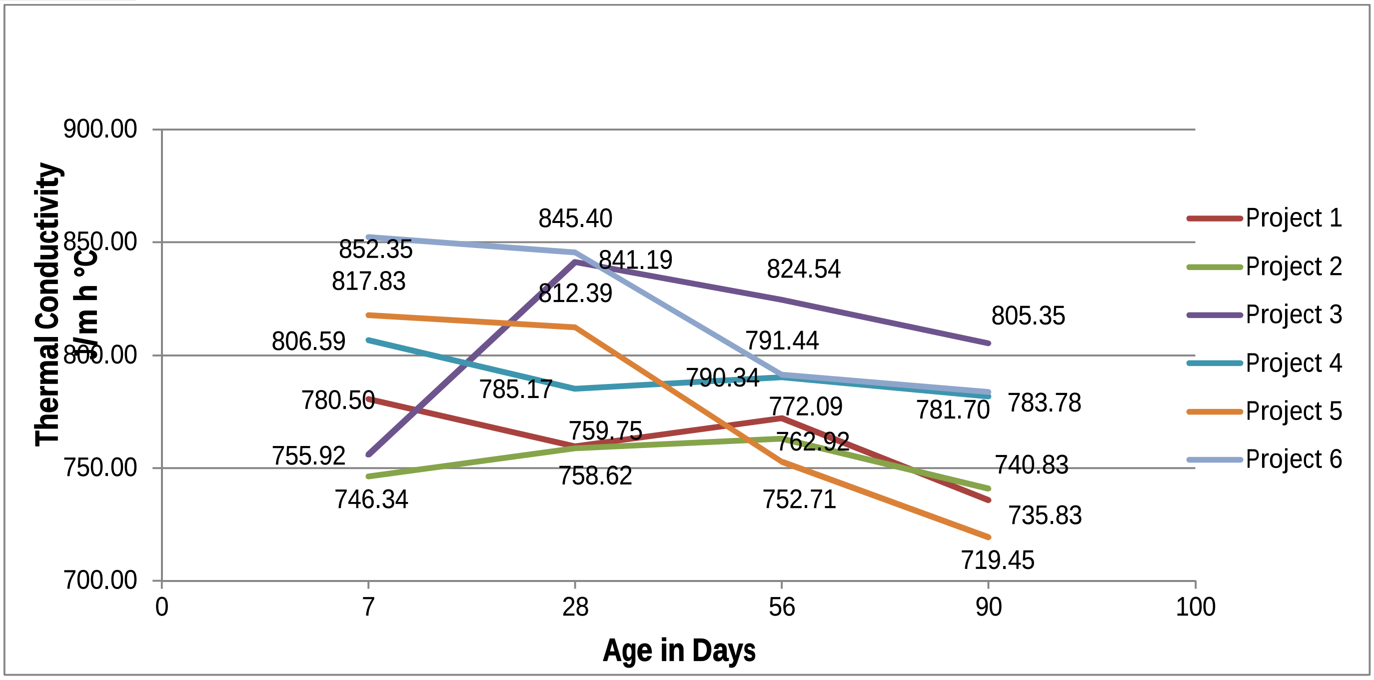

Fig. 10: Specific Heat at 7, 28, 56 and 90 days

3) Discussions

Thermal Conductivity - Figure 8 illustrates the thermal conductivity of six mix designs at curing ages of 7, 28, 56, and 90 days under saturated conditions. It was observed that the thermal conductivity of all mixes increased after 28 days compared to 7 days, with the exception of mix 3. This anomaly may be attributed to the drying of moisture from the voids on the surface of the cubical concrete specimen, either through the use of towels or due to evaporation. Similarly, after 56 days, the thermal conductivity of all mixes increased relative to 28 days, except for mix 2, which may be affected by the same factors previously mentioned. Furthermore, the thermal conductivity of all mixes was found to have increased after 90 days when compared to the 56-day results.

Thermal Diffusivity - Figure 9 illustrates the thermal diffusivity of six mix designs at curing ages of 7, 28, 56, and 90 days under saturated conditions. It was observed that the thermal diffusivity of all mixes increased after 28 days compared to 7 days, with the exception of mixes 2 and 3. This anomaly may be attributed to the drying of moisture from the voids on the surface of the cubical concrete specimens, either through the use of towels or due to evaporation. Furthermore, the thermal diffusivity of all mixes continued to rise after 56 days in comparison to 28 days. Likewise, after 90 days, an increase in thermal diffusivity was noted for all mixes relative to 56 days, with the exception of mix 4, which may be influenced by the same factors previously mentioned.

Specific Heat - Figure 10 illustrates the specific heat values of six mix designs at curing ages of 7, 28, 56, and 90 days under saturated conditions. It was observed that the specific heat of all mixes decreased after 28 days in comparison to 7 days, with the exception of mixes 2 and 3. This variation may be attributed to the drying of moisture from the voids on the surface of the cubical concrete specimens, either through the use of towels or due to evaporation. Likewise, after 56 days, the specific heat of all mixes showed a decline relative to 28 days, except for mixes 2 and 4, which may be influenced by the same factors previously mentioned. Furthermore, a further decrease in specific heat was noted for all mixes after 90 days compared to 56 days.

IV. CONCLUSION

This investigation aimed to evaluate the influence of age under saturated conditions on the thermal properties of concrete, focusing on Thermal Conductivity, Thermal Diffusivity, and Specific Heat. The results derived from the extensive testing yield the following conclusions:

1) The Thermal Conductivity of concrete is affected by both age and moisture, showing an upward trend with age when assessed under saturated conditions.
2) There is a notable increase in the Thermal Diffusivity of concrete as age advances when tested under saturated conditions.
3) However, the Specific Heat of concrete experiences a decline with age under saturated conditions.

V. ACKNOWLEDGEMENT

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