# Investigating the Thermal Conductivity of Different Concrete and Reinforced Concrete Models with Numerical and Experimental Methods

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*Abstract:* - Concretes and reinforcement concretes have been important for years in structure technology. Although the mechanical properties of concretes and reinforced concretes are the most crucial criteria for preference, the thermal properties are also important in recent years owing to developments in renewable energy and net zero energy building technologies. In this study, thermal conductivity of concretes and reinforced concretes were investigated by numerically and experimentally. Two reinforcement bars were settled in geometries by different bar diameters as 10 mm and 12 mm. Also a concrete geometry was constituted. The correlations between the three different geometries were shown in a graph. The thermal conductivity values range between 0.991 W/mK and 1.09 W/mK for experimental study. Furthermore, the thermal conductivity values range between 0.993 W/mK and 1.096 W/mK.

*Key-Words:* Thermal conductivity, Experimental study, Numerical Study, Reinforced Concrete, Concrete

## 1 Introduction

Concrete is a composite material which includes various materials such as cement, aggregate and some chemical components. Although the concrete resists to high pressure stress, it is very weak for tensile force. In order to resist to tensile force, some reinforcement materials are added to concrete in structure technology. Hereby, reinforced concrete has been using in structures for long years.

Generally, the mechanic properties are important for preference of reinforced concrete. However, in recent years, reinforced concrete has an importance for different aims. It has a significant role in vertical ground source heat exchangers and some net zero energy building projects. Namely, the other properties of reinforced concretes such as thermal properties have been important since these applications and approaches started.

Many studies were applied related to thermal or thermo physical properties of concretes. Tasdemir [1], studied the thermal properties of light concretes. She investigated three different light concretes and obtained the thermal conductivities of these concretes. Yun et al. [2], evaluated the thermal conductivities of thermally insulated concretes. They tested the four different aggregate for concrete. They presented the difference between thermal conductivities of concretes which include different aggregate in line graphs. Toman and Cerny [3] investigated the thermal conductivities of high performance concretes in wide temperature and moisture ranges. They studied between 200$^{o}$C-1000$^{o}$C temperature range and %0-%8 kg/kg moisture range respectively. According to their results, the high performance concretes have the minimum thermal conductivity value nearly at 400$^{o}$C. The thermal conductivity and diffusivity of concretes were investigated in wide ranges by Carman and Nelson [4]. They had enormous number of test for various concrete types. They presented the thermal conductivities and diffusivities of different concretes in table. Also, the amount of components that belong to concretes were shown in same tables. Kizilkanat et al. [5], studied the thermo physical properties of concrete in high temperature. They investigated the various effect related to thermal properties of concretes. Moreover, thermal conductivity of concretes are used in ground source heat pump applications [6], [7].

Up to now, although there have been many studies related to thermal properties of concrete, there was no study that investigate the thermal conductivity of concrete or reinforced concrete according to bar volume/total geometry volume. In this study, the thermal conductivities of concrete and reinforced concrete were investigated both experimentally and numerically. Herewith, the correlation related to volume ratio of reinforcement materials in concrete geometry can be evaluated. The obtained correlation could be useful for other heat pump or net zero energy buildings projects.

Under the study, three different concrete models were constituted. These are the CW (concrete without any reinforcement material), CW10 (the concrete with 10 mm diameters reinforcement bars) and CW12 (the concrete with 12 mm diameters reinforcement bars) respectively. After experimental study, the same models were created in a CFD package program and they were analyzed in same conditions with experimental study. Finally, the results of two methods were comprised. According to comprising, a thermal conductivity correlation was presented related to volume of reinforcement materials in concrete. Two different heat fluxes values were applied the models both experimental and numerical studies.

# 2 Problem Formulation

Fourier heat conduction equation:

$$Q.\ L = \Delta T.\ A.\ k \quad (1)$$

Continuity Equation:

$$\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \quad (2)$$

Momentum Equation in x direction:

$$\rho\left[u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right]=-\frac{\partial p}{\partial x}+\mu\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right] \quad (3)$$

Momentum Equation in y direction:

$$\rho\left[u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right]=-\frac{\partial p}{\partial y}+\mu\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right] \quad (4)$$

Momentum Equation in z direction:

$$\rho\left[u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right]=-\frac{\partial p}{\partial z}+\mu\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right] \quad (5)$$

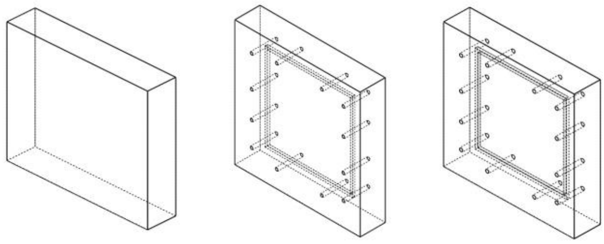
Energy Equation

$$u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}+w\frac{\partial \theta}{\partial z}=\alpha\left(\frac{\partial^2 \theta}{\partial x^2}+\frac{\partial^2 \theta}{\partial y^2}+\frac{\partial^2 \theta}{\partial z^2}\right) \quad (6)$$

# 3 Problem Solution

## 3.1 Experimental Study

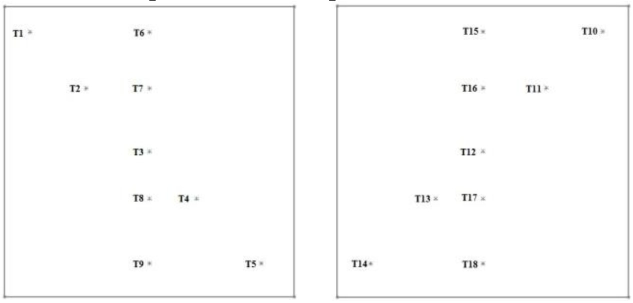
Three different concrete models were constituted for this study. Two of these models include 10 mm diameters and 12 mm diameters reinforcement bars (CW10 and CW12). The other model did not include any bars(CW). The concrete class was C30. The experimental setup was build up according to ISO 8302 Standard [8]. The models had 50x50x10cm size and the length of reinforcement bars were 9 cm. Figure 1 shows the concrete models.



(a) (b) (c)

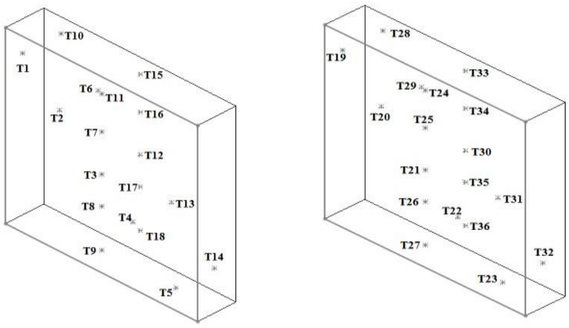
Figure 1. The concrete and reinforcement concrete models, (a) CW-(b) CW10-(c) CW12

The models had two 50x50 cm surfaces. For each experiment, the two same models were used. The heating plate was settled the middle of these two geometries and heat fluxes applied to the two geometries by the heating plate. Two same models had totally four 50x50 cm surfaces. Two of these surfaces contacted to heating plate. The other surfaces contacted to room air. Heat fluxes were applied to heating plate and the contacting surface transferred the heat the other surface by conduction. Meanwhile, a part of heat may loss by lateral surfaces. In order to prevent the heat loss, the lateral surfaces were covered by insulation materials. Thermocouples were settled the both main and lateral surfaces. Nine thermocouples were settled the 50x50 cm surfaces. Also four thermocouples were settled to lateral surfaces in order to measure the heat loss. In addition, a thermocouple was used to measure the air temperature. That is to say, forty-one thermocouples were used for each experiment. Figure 2 and Figure 3 show the settlement of thermocouples to surfaces of models. Also Figure 4 shows the experimental setup.




(a) (b)

Figure 2. The thermocouples settlement on two surfaces just for one concrete




(a) (b)

Figure 3. The isometric views of thermocouple settlement for two geometries, (a) the geometry above the plate- (b) the geometry under the plate

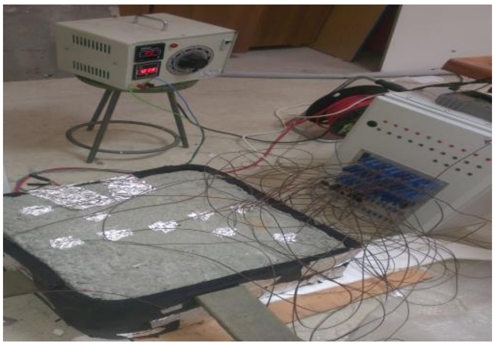


Figure 4. The experimental setup

The heat fluxes were applied to heating plate by using variac. Table 1 shows the heat inputs for each experiment.

Table 1. The heat inputs for each model

| Model Name | Case 1 | Case 2 |
|---|---|---|
| CW | 31.54 W | 54.00 W |
| CW10 | 30.75 W | 52.00 W |
| CW12 | 30.22 W | 54.40 W |

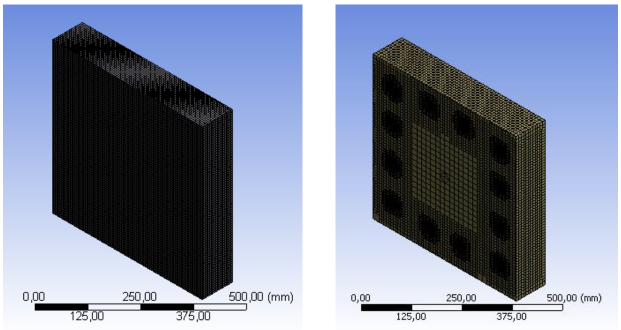
The temperatures were obtained by the thermocouples. The surface temperatures were obtained by the average temperatures of thermocouples for each surface.

The thermal conductivities of models were obtained by fourier heat conduction equation. The equation was shown in (1)

$Q$ is the heat input to geometries from heatin plate. $L$, is the width of concrete geometry and $L$ is 0.1 m for this study. $A$ is the heat transfer surface area and it is 0.25 $m^2$. $\Delta T$ is the temperature difference between two 50x50 cm surfaces. The temperature differences were obtained for all experiments. Owing to these temperature differences, $k$, the thermal conductivity (W/mK), was determined.

## 3.2 Numerical Study

For numerical study, the ANSYS CFD package program was used. The same geometries were created in design modeler module. In meshing module, the assembly meshing was used for all geometries. Figure 5 shows the mesh grids for all models.




(a) (b)

Fig 5. The mesh grids for models, (a) CW-(b) CW10 and CW12

The models were analyzed according to some boundary conditions. Table 2 illustrates the boundary conditions for CFD study.

Table 2. The boundary conditions

| Surface | Boundary Conditions |
|---|---|
| Heating plate surface | Wall(heat flux input) |
| Lateral surfaces | Wall(adiabatic walls) |
| Room surface | Wall(convection) |
| Bar bodies in geometry | Interior walls |

As shown in Table 2, the lateral surfaces were defined as adiabatic walls. Namely, It was an assumption that there was no heat loss from lateral faces. In order to be true for this assumption, the heat loss was determines from the lateral surfaces in experimental studies. Hereby, the net heat transfer from the heating plate surface to room surface was obtained. The heat flux to heating plate surface was entered as net heat input. For room surface, the convection boundary conditions were assumed. The room temperature and the heat transfer coefficient values were entered the program.

Numerical solutions have been obtained by solving the governing integral equations for the conservation of mass, momentum and energy with the use of ANSYS CFD package program which discretizes these equations employing the control volume technique [9]. This technique works by performing the integration of the governing equations over a control volume, and then discretization of these equations on each control volume [9]. The governing equations (conservation of continuity, momentum and energy equations) for laminar flow can be written as (2), (3), (4), (5), (6),

### 3.3 Results

In this study, the thermal conductivities of various concrete and reinforced concrete geometries were investigated with numerical and experimental methods.

The thermal conductivity values were shown in Table 3. According to Table 3. The thermal conductivity was 0.991 W/mK for CW experimental study. In numerical study, they were 0.994 W/mK and 0.993 W/mK for Case 1 and Case 2 respectively. The thermal conductivity was found 1.03 W/mK for CW10 experimental study. At the same conditions, thermal conductivities were found 1.04 W/mK and 1.045 W/mK for Case 1 and Case 2 respectively. Lastly, the thermal conductivity was 1.091 W/mK for CW12 study. They were 1.096 W/mK and 1.085 W/mK for Case 1 and Case 2.

Table 3. *k* (W/mK)Values both experimental and numerical studies.

| Model | Exp. | Case 1 | Case 2 |
|---|---|---|---|
| CW | 0.991 | 0.994 | 0.993 |
| CW10 | 1.03 | 1.04 | 1.045 |
| CW12 | 1.091 | 1.096 | 1.085 |

Figure 6 illustrates the graphs of thermal conductivities by numerical and experimental studies.

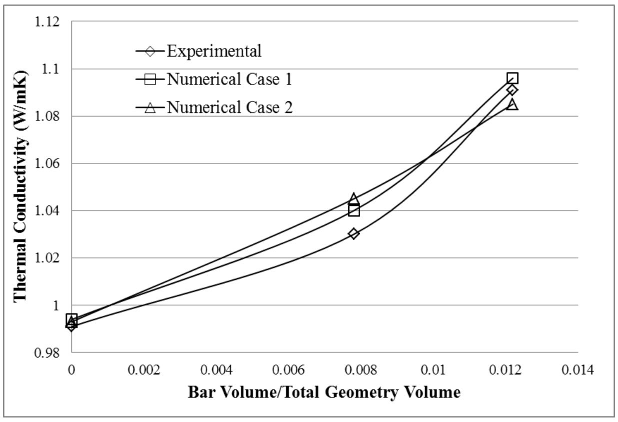
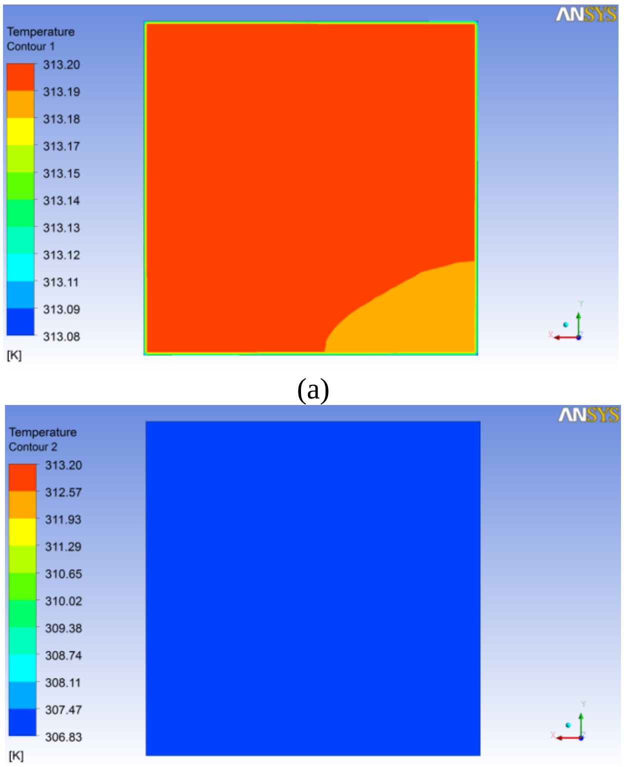



Figure 5. The correlations of experimental and numerical studies

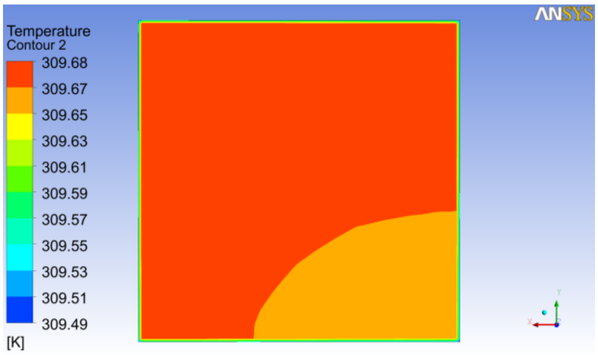
Figure 5 shows that the thermal conductivities increased dramatically for both experimental and numerical studies.

Many numerical results were obtained by CFD analyzes. The temperature distributions of surfaces were determined by using CFD-Post program in ANSYS Package program. Figure 6,7,8,9,10,11 and 12 illustrate that the temperature distribution of all numeric cases.

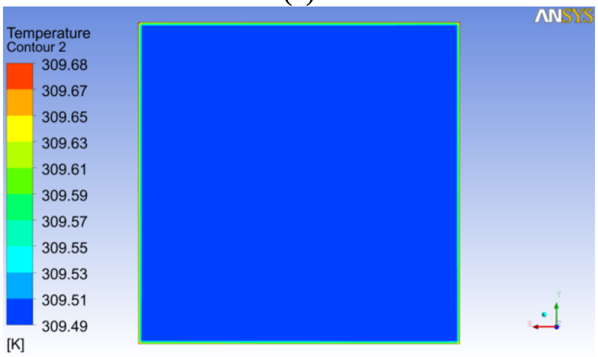



(b)

Figure 6. The temperature of heating plate(a) and room surface(b) for CW model in Case 1 respectively

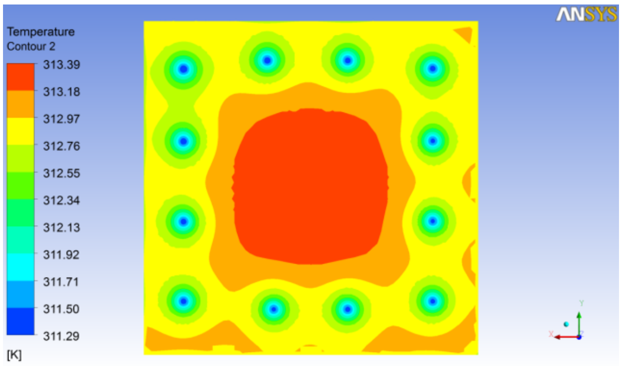



(a)

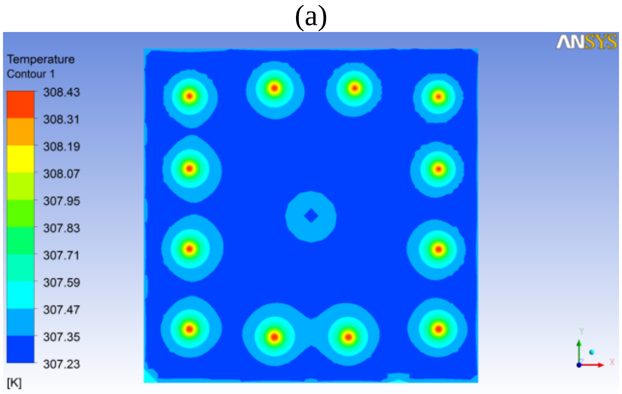



(b)

Figure 7. The temperature of heating plate(a) and room surface(b) for CW model in Case 2 respectively

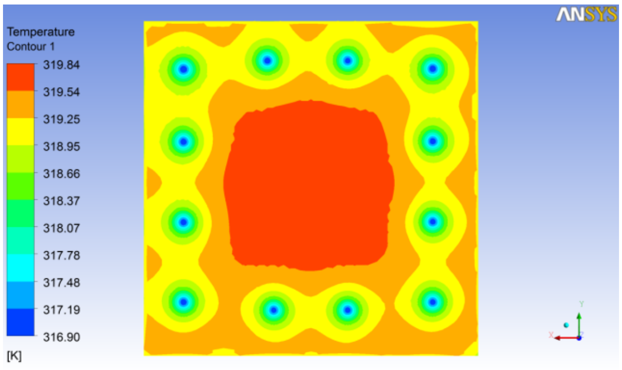



(a)

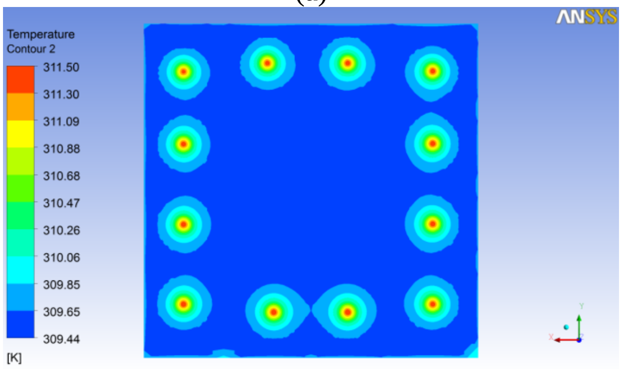



(b)

Figure 8. The temperature of heating plate(a) and room surface(b) for CW10 model in Case 1 respectively

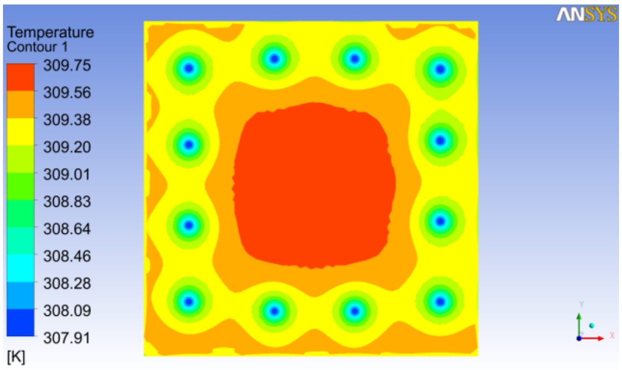



(a)

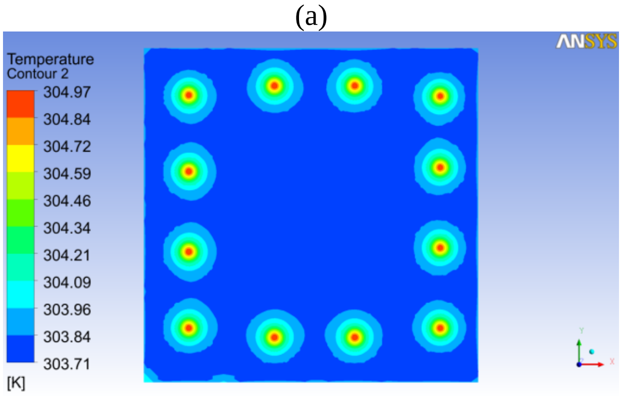



(b)

Figure 9. The temperature of heating plate(a) and room surface(b) for CW10 model in Case 2 respectively

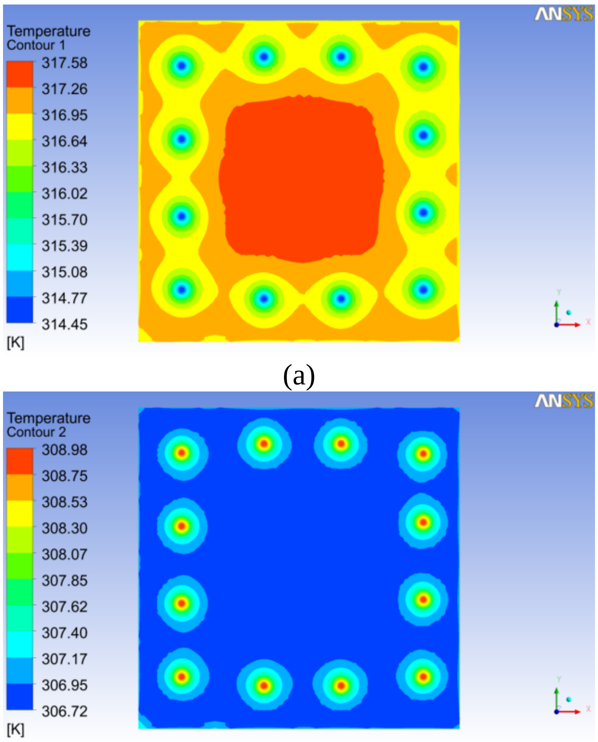



(a)




(b)

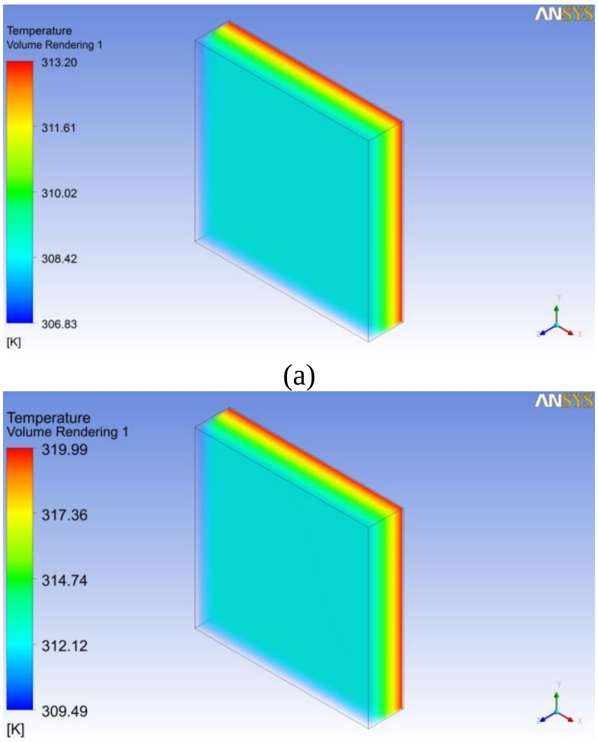
Figure 10. The temperature of heating plate(a) and room surface(b) for CW12 model in Case 1 respectively




(a)

(b)

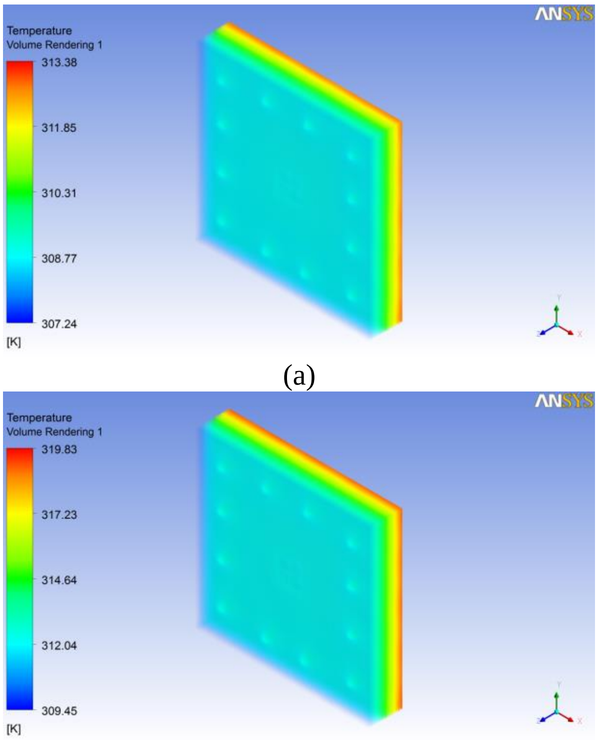
Figure 11. The temperature of heating plate(a) and room surface(b) for CW12 model in Case 2 respectively




(a)

(b)

Figure 12. The temperature distribution in CW model for Case 1(a) and Case 2(b)




(a)

(b)

Figure 13. The temperature distribution in CW10 model for Case 1(a) and Case 2(b)

The numerical models were validated by comprising experimental data. Thus, the validated models allowed us to show temperature distribution on surfaces and temperature distribution in volume. In addition to surface temperatures, the temperature distributions in volumes were also crucial.

The results of validated numerical models give information about the heat transfer in concrete and reinforced concrete geometries. Figure 6 and Figure 7 shows that the temperature distribution is steady for concrete. However, Figure 8,9,10 and 11 show that the temperature difference was occurred by reinforced concretes. The reinforced bar provide the heat transfer faster than just concrete geometry. Increasing the bar volume in total volume provide to rising in heat transfer rate.

In addition the temperatures on surfaces, also temperature distributions on volumes are significant. Figure 12,13,14,15,16 and 17 illustrate that the temperature distribution in volumes.

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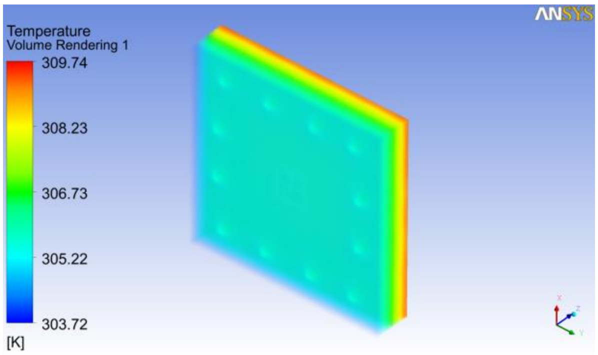
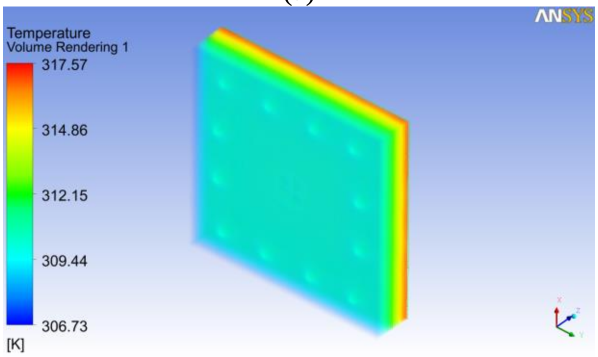



(a)




(b)

Figure 14. The temperature distribution in CW12 model for Case 1(a) and Case 2(b)

Figure 12, 13 and 14 show that reinforcement bars had important effect on surface temperatures and heat transfer rate.

## 4 Conclusion

The effect of reinforcement materials on thermal conductivity of concrete were investigated both numerically and experimentally in this study. The conclusions were specified below.

- The reinforcement bars had crucial effect on thermal conductivity of concretes.
- The numerical studies were validated by experimental data. Owing to this validation, other reinforcement geometries may be analyzed numerically further.
- The thermal conductivities were determined two different cases in experimental study. Both of these studies show up constant thermal conductivity values for CW, CW10 and CW12 models. These are 0.911 W/mK, 1.03 W/mK and 1.09 W/mK for experimental data.
- In numerical study, two case were studied like in experimental study. However, the thermal conductivity values show a little difference between two cases. The values are 0.994 W/mK, 1.04 W/mK and 1.096 W/mK for Case 1. Also for Case 2, the values were 0.993 W/mK, 1.045 W/mK and 1.085 W/mK.
- The validated numerical studies allow us to show the temperature distributions in volumes or on surfaces.
- Owing to validation, other reinforcement bar diameters can be analyzed by numerical models.

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