Effect of Sample Length on the Time Needed to Reach the Steady State Case

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Abstract

In this study, ANSYS-14 was used to study the effect of the length of the sample on the time needed to reach steady state (S.S.t) for the transient heat transfer. Three samples were studied in different lengths (15, 30 and 45 cm), 2 cm high, in addition to the selection of three materials with different thermal properties and applied to different lengths. One side of the three samples was exposed to a temperature at 100 ° C, while the other side was exposed to thermal load at 25 ° C and the sample was isolated from the top and bottom surfaces. The objective of this study is to determine the effect of the time reach to the steady state when changing the length of the sample exposed to constant thermal load and materials, depending on the distance from the hot face of all lengths at a number of points (3, 6, 9 and 12) cm. From the results of the time obtained numerically from the ANSYS-14 program, the time to reach the steady state was determined when the difference between the sample temperature reached with the previous grade of 0.001.The results indicated that the time required to reach the steady state (S.S.t) increases by increasing the length of the sample in the selected points when constant thermal diffusivity (α) ,where the time needed to reach the steady state of the copper material ranged between (879-1085) seconds at a length of 15 cm and (2112- 3005) seconds at length 30 cm and (2871-4937) seconds at a length of 45 cm as well as the results showed that the time required to reach the steady state increased with the thermal diffusivity decrease where the time required to reach the steady state of the copper of the highest thermal diffusivity ranged between (879-4937) seconds for all lengths while the time required to reach the steady state of the material of the lowest thermal diffusivity (hardboard) is between (168400-1078000) seconds.

Keywords: Thermal Diffusivity (α), Transient analysis, Heat conduction problems, Thermal conductivity, Heat transfer numerical methods.

Nomenclature

S.S.t	time of steady state (second)
S.S.T	temperature of steady state (° C)
α	thermal diffusivity (m^2/sec)
L	Length of sample (m)
T	Temperature (° C)
K	Thermal conductivity (W/m.ºC)
ρ	Density (Kg/m^3)
C	Specific heat (J/Kg.ºC)
t	time (sec)
x	Distance (m)

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1-Introduction

The transient heat transfer during solids depends on a some of variables such as thermal properties (heat capacity, density and thermal conductivity) of these materials and the amount of thermal load exposed to it, the shape of the sample, as well as the shape and distribution of porosity within the material.Where all these variables will contribute to increase the rate of heat transfer due to differences in temperatures.

One paper studying the time required to reach the steady state from the effect of the temperature difference between two faces of sample (a parallelogram shape of length =15 cm, width=1 cm and height=1 cm) in transient case. This study used four materials of different thermal properties and three different thermal load on one face as well as a convection load to other face .The results explained the increase in steady state time with increasing the temperatures difference between two faces and its decrease with increase of thermal diffusivity [1].Another study which tried to explain that the relationship between thermal diffusivity of any material and of its thermal behavior when subjected to thermal load in transient case. In this study, many of lightweight materials were used which have low thermal conductivity as suggestion materials. Results explained that the rising of sample temperature when increasing of thermal diffusivity with decreasing in time and an inverse relationship between thermal diffusivity with the steady state time. The temperature decrease when moving away from hot face at constant thermal diffusivity [2].Numerical study was used to evaluate the thermal initiation time for samples have different lengths and different thermal properties at different distances along the sample from heating source. The results of first study explained the thermal initiation time increase with move away from the heating source at constant thermal diffusivity and its decrease with increase of thermal diffusivity at constant distance from heating source. The results of second study explained the different lengths of sample has no effect on the thermal initiation time at points have same distance from heating source[3].

One of the numerical study explains the effect of the variation of the value of thermal conductivity on the temperature distribution through a wall exposed to a constant heat generation by using a MATLAB program for a wide range of temperatures and different materials. The result of study showed that the shape of the distribution of temperatures take a linear relationship for wall thickness less than 40 cm then begin to take curvatures shape after that as well as from result concluded the effect of variation of thermal conductivity didn't appear clearly except in high temperatures [4].Analyses of transient and steady state are studied for Cast iron and Aluminum composite material of brake drum by using a finite element model. Result obtained that the thermal deformation and maximum temperature in aluminum composite is less than the cast iron brake drum, when comparison between them[5].Numerical and analytical study that concentrated on load distribution to get specific results on the resulting temperature distributions for a variety of working conditions. Such results could form the basis for enhancing the cooling strategy [6].A solution has been found for the problem of transient heat stress in the elliptical ring with multiple layers in the radial direction with the internal thermal source and independent of the time in each layer. The solution is achieved by using an integrated conversion technique similar to Vodicka method in considering the function of string expansion in terms of eigenfunction To solve the partial differential equation of thermal conductivity in elliptic coordinates. The results were obtained numerically for temperature and thermal pressure[7].

A typical solution for transient thermal conductivity equation was obtained in a new conical-shaped composite shell by combining two analytical methods by an integrated transformation in the angular direction of thermal conductivity equation and then solved using the method of separating the variables. To ascertain the accuracy of the current analytical solution, the analytical results of both methods were compared. It was concluded that the solution is applicable in some industrial areas such as aviation tools and cooling cooling fins[8].Transient thermal conductivity through two-layer or three-layer hollow cylinders has been developed in a clear and closed manner by modern analytical methods rather than traditional methods and multiple calculations. This proposed method is effective in calculation because it contains binary matrices in the solution process[9].To know the value of effective thermal conductivity is difficult because it depends on the temperature level and the temperature is included through the bed, in addition to the structure of the pebble packing. This research presents a test designed for this problem in an accompanying manner that combines physical measurements and simulation of computational fluid dynamics (CFD) to separate radiation contributions and heat transfer by conductivity, as well as the effects of the wall. Preliminary results observed in the experimental results provided a better understanding of basic heat transfer phenomena[10].

To describe the thermal diffusion distribution, a new method was proposed based on the method of separation of variables and the orthodontic expansion technique for temperature prediction through the MTPS thermal-thermal protection system. This method adopted a numerical solution that divides the whole heat transfer process into a number of time steps to solve the problem Boundary conditions that differ with time to describe the distribution of thermal propagation through the thickness direction. The results gave a good agreement by comparing them to the FEM method [11].

The Laser Flash Analysis (LFA) was used to measure thermal diffusion and to study the effect of silicon in a binary alloy of aluminum and silicon. To obtain a stable structure and remove dissolved silicon the cast samples were grinded at 345 ° C. The results showed increased thermal diffusion with reduced dissolved silicon atoms in the aluminum matrix through the analysis of thermally treated samples by LFA in dynamic mode[12].To study the change of thermal diffusivity with temperature, two independent data groups of crystalline rocks from different regions were used. This study was focused to build a relationship between thermal diffusivity and thermal conductivity at any temperatures. After a comparison of results of this study with data from two crystalline samples, we conclude the want for additional data, which will assist tell uncertainties [13].Filmwise condensation on horizontal surface with asymmetric structures is studied numerically based on the gases kinetic theory. The verification of the model from the experimental data and a parametric study was done. The results of experiments gave the increase of the condensate toward the sharper incline as well as the parametric studies gave the increase of the condensate when the angle of the ratchet is increased [14].

Ansys workbench program was done to calculate the heat transfer through the radiator with water depend on CuO Nano fluid. The performance of heat transfer was enhanced when the volume fraction of CuO rises .To improve the performance of heat transfer, a project of experiment way optimal length was used without affecting pumping power [15].The ANSYS program is applied to determine the heat flow rate and heat flux by analyzing the thermal behavior of two composites materials (MS-Hylum-Wood and MS-Fiber Glass- Brick). Result of this study showed that the MS-Hylum-Wood has lowest temperature distribution and heat flux than the MS-Fiber Glass- Brick [16].For estimating the behavior of the car rotor brake disc under sharp braking conditions; a thermal transient analysis was done. In this study ANSYS program was applied to find the distribution of temperature, difference of the stresses and deformation through the form of disc brake. This study focused to choose convenient light material compared with cast iron. The results explained the S2 glass fiber is convenient material for braking task. Depending on the rigidity criteria and strength the design of brake disc is secure because all the data that got from the examination lower than permissible values[17].Four hang samples of graphene with various widths were simulated between the heat sink and a thin membrane sensor. When comparing the temperature difference got from the sensor with or without graphene and the temperature difference that got from thermal analysis, conclude that the thermal conductivity for graphene with large width more than thin sample[18]. graphene gives ideal test stage for examining thermal conductivity in 2-dimension because it have higher thermal conductivity, so is necessary for use in phonon transfer in materials that have small dimensions. Experimental computations and non-equilibrium emulations of thermal conduction in hanging one-layer graphene based on both of specimen length and temperature. Thermal conductivity continues to increase and remains logarithmically spaced with specimen length even for specimen lengths much greater than the average phonon level and this results provides a basic understanding of thermal transfer in 2-dimension [19]To solve unsteady heat conduction troubles in many-layer panels, a way of one-dimensional Finite Difference was used and modified of its program to get foamed concrete thermal properties as well as to imagine the temperature growth along the slab thickness of foamed concrete. Model was tested from little scale heat transmit during slabs of foamed concrete through comparison experimental and predicted temperature sketches. The results showed a significant convergence between the calculated results of the program and the experimental results [20].

This review displays the great amount of many analytical and numerical studies to explain the thermal initiation time, the effect of variation of thermal conductivity, load distribution, heat transfer, the evaluation of heat flow and the distribution of temperature. As well as study the variation of width and the time required to reach the steady state. This research concentrated on demonstrating the influence of the length on the time needed to reach the steady state. The time to reach steady state was determined when the difference between the temperatures of the sample reached with the degree before it was 0.001 as a rule for reaching the steady state on samples that have variable length and variable thermal properties.

2-Requirement & modeling

The distribution of temperatures through the selected points on the samples that have different lengths is described by the unsteady one-dimensional heat conduction equation [21, eq. (1)]:

$$k\ \frac{\partial^2 T}{\partial x^2} = \rho\ c\ \frac{\partial T}{\partial t} \qquad \text{---------------}\ (1)$$

A study was carried out by using ANSYS-14(APDL) to find the steady state time of samples exposed to thermal load in unsteady heat transfer case .Samples used have three different lengths (15,30 & 45)cm with height 2cm, that described in figure (1). Each sample applied for three materials (Copper, Hardboard (Medium) and Slate Tiles) that have different thermal properties, as explained in table (1). The sample was isolated from the upper and lower surface and assumed no generation of heat .The heat transfer was applied in one dimension along the x-direction of samples. One face of sample exposed to 100°C while the other face exposed to convection at 25°C. Another thermal and boundary conditions were used in study illustrated in table (2).

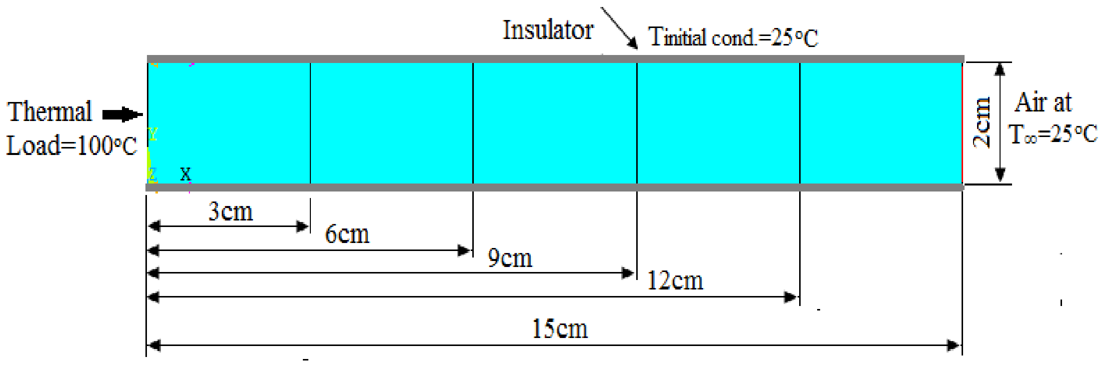


Figure (1-a) L=15cm the selected points at X=(3,6,9&12)cm

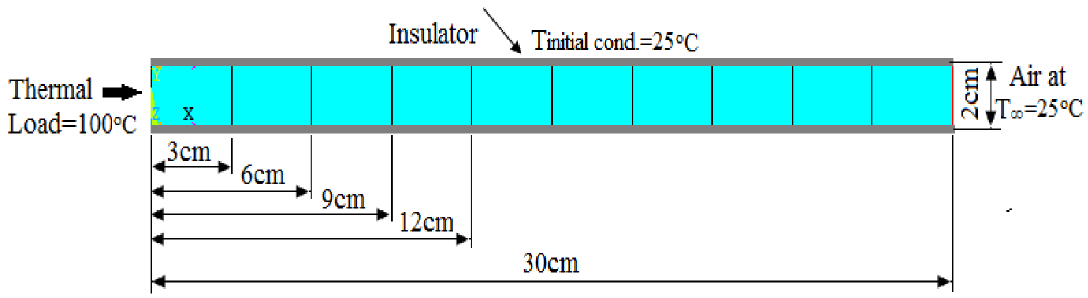


Figure (1-b) L=30cm the selected at X=(3,6,9&12)cm

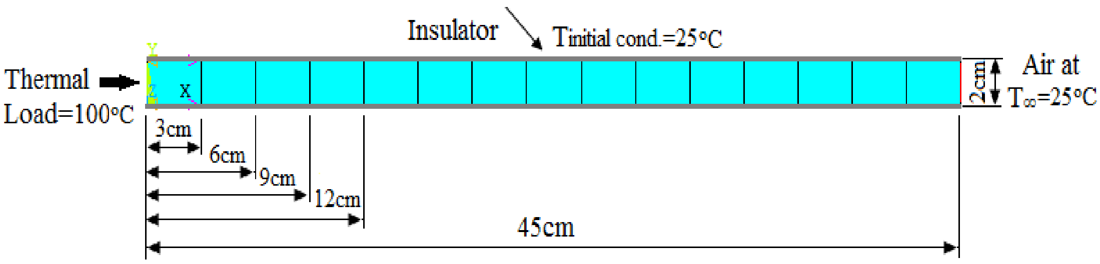


Figure (1-c) L=30cm the selected points at X=(3,6,9&12)cm

Figure (1) Specification of samples with the thermal conditions

Table (1) Thermal properties of materials used [22], [23]

Thermal properties of materials		K (W/m.°C)	ρ (Kg/m^3)	Cp (J/Kg.°C)	(α) (m^2/sec)
Materials	Copper	200	8900	418	α=5.38E-05
	Slate Tiles	2	2700	753	α=9.84E-07
	Hardboard (Medium)	0.08	600	2000	α=6.67E-08

Table (2) Ansys constants and Boundary Conditions

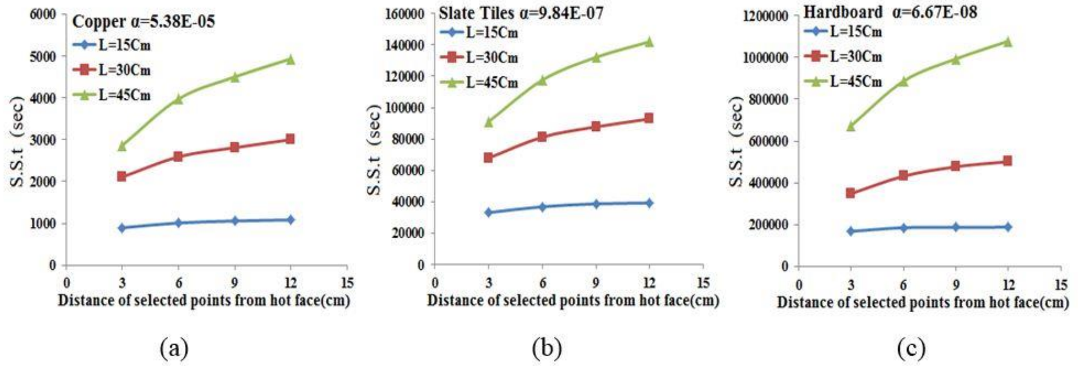
<table>
<tr><td>Sample length (L)</td><td colspan="3">0.15 m</td><td colspan="3">0.30 m</td><td colspan="3">0.45 m</td></tr>
<tr><td>sample width</td><td colspan="9">0.02m</td></tr>
<tr><td>Thermal load in the right side (°C)</td><td colspan="4">Convection at T∞= 25°C</td><td colspan="5">h_{conv}.=10W/m².°C</td></tr>
<tr><td>Thermal load in the left side (°C)</td><td colspan="9">100</td></tr>
<tr><td>Temp. difference between two side (ΔT) (°C)</td><td colspan="9">75</td></tr>
<tr><td>Initial condition of sample</td><td colspan="9">T_{initial cond.} = 25 °C</td></tr>
<tr><td>Element edge length</td><td colspan="9">0.03m (mesh= medium)</td></tr>
<tr><td>Preferences for filtering</td><td colspan="9">Thermal</td></tr>
<tr><td>Analysis Type</td><td colspan="9">Transient</td></tr>
<tr><td>Materials</td><td colspan="3">Copper</td><td colspan="3">Slate Tiles</td><td colspan="3">Hardboard (Medium)</td></tr>
<tr><td>length of sample (m)</td><td>0.15</td><td>0.30</td><td>0.45</td><td>0.15</td><td>0.30</td><td>0.45</td><td>0.15</td><td>0.30</td><td>0.45</td></tr>
<tr><td>Number of nodes</td><td>5</td><td>10</td><td>15</td><td>5</td><td>10</td><td>15</td><td>5</td><td>10</td><td>15</td></tr>
</table>

3-Results and Discussion

The steady state time was selected from results of ANSYS program, when the difference between the temperatures of the model reached with the previous temperature was 0.001, i.e. the temperature of the sample has very small change with the time.

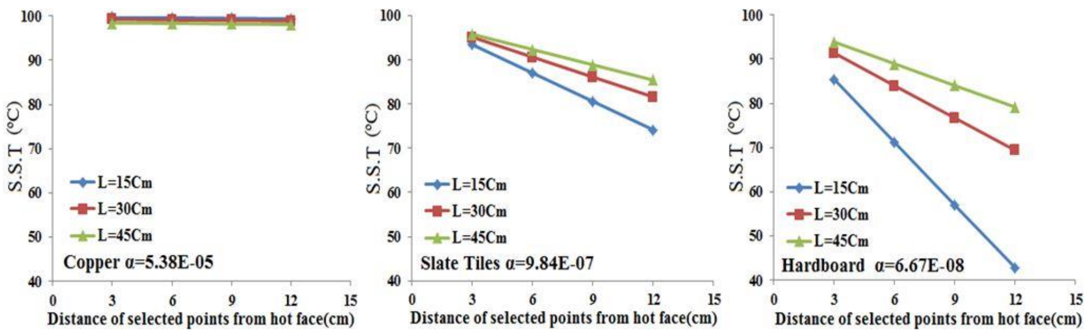
Figure 2 (a) ,at X=3cm We notice the time required to reach the steady state(S.S.t) increases in this location when increasing the length (L) of the sample, in spite of the fact that the distance from the hot face is constant for all samples and the temperatures difference between the sample ends is also constant . The only reason for this effect as the length (L) of the sample was increased; that the difference in temperatures between the sample ends will decrease i.e. the rate of heat transfer (driving force) will decrease.

The influence of another variable, like distance from the hot face and the amount of thermal diffusivity was evident in the time of arrival in the steady state (S.S.t) through the shape.



Figure(2) Effect of distance on Steady state time (S.S.t.)

Figure (3) Shows the effect of the length (L) of the sample at the temperature of the steady state (S.S.T.) is assumed to be an inverse, but this effect was not apparent in copper because of its high thermal diffusion. The effect of the distance from the hot face also showed clearly in the material that have low thermal diffusivity as in the hardboard and did not notice its effect in copper because of its high diffusivity.



Figure(3) The effect of distance on temperature of Steady state (S.S.T.)

Figure (4) explains the relationship of steady state time (S.S.t) with distance from hot face, which explains as follows:-

1- As the length (L) of sample is constant, the main variable that effected on the value of S.S.t is the thermal diffusivity of material, where notice that the values of S.S.t of copper for all points is so small and take a straight line shape parallel to x-axis if compare with the values of hardboard (medium) and slate tiles .The reason because the thermal diffusivity of copper more than the other materials and this appear clearly in this figure.

2-In terms of sample length (L), we notice that the values of S.S.t for all points(3,6,9&12) may be convergent for every material where take a straight line shape parallel to x-axis as in figure4 (a) at length=15cm. Either when the length(L) of the sample equal to 30cm and 45cm, also we notice convergent of the values of S.S.t for all points for each of the copper and slate tiles but this values more than the S.S.t values at length=15cm. S.S.t values for all hardboard points increase with the length of the sample as shown in Fig. 4 (b, c) due to their low thermal diffusivity when compared to the copper and slate tiles.

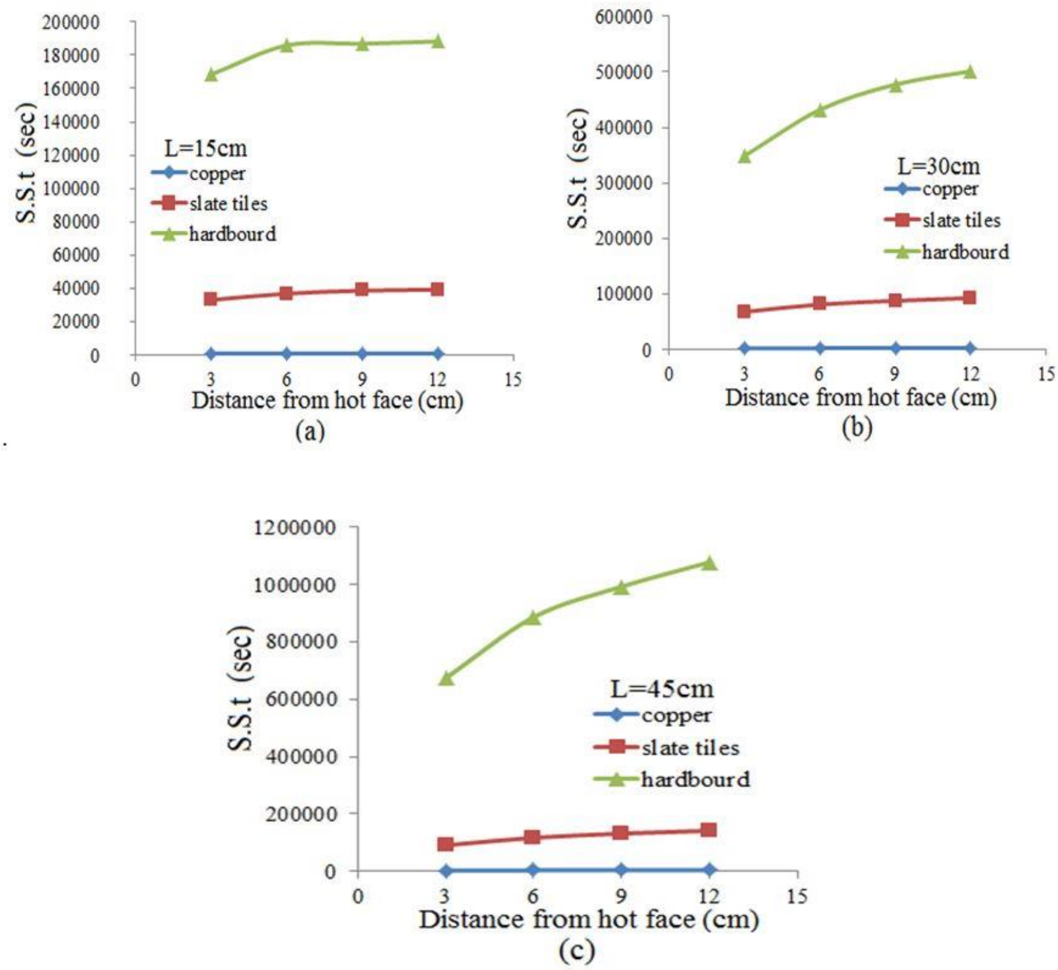


Figure 4(a, b&c) the effect of samples length on Steady state time (S.S.t.)

Figure (5) shows that the relationship between the distance from the hot face and the steady state temperature (S.S.T.) is an inverse relation that takes the form of a straight line, and the straight-line slope will decrease when increasing the length (L) of the sample and increasing the thermal diffusivity.

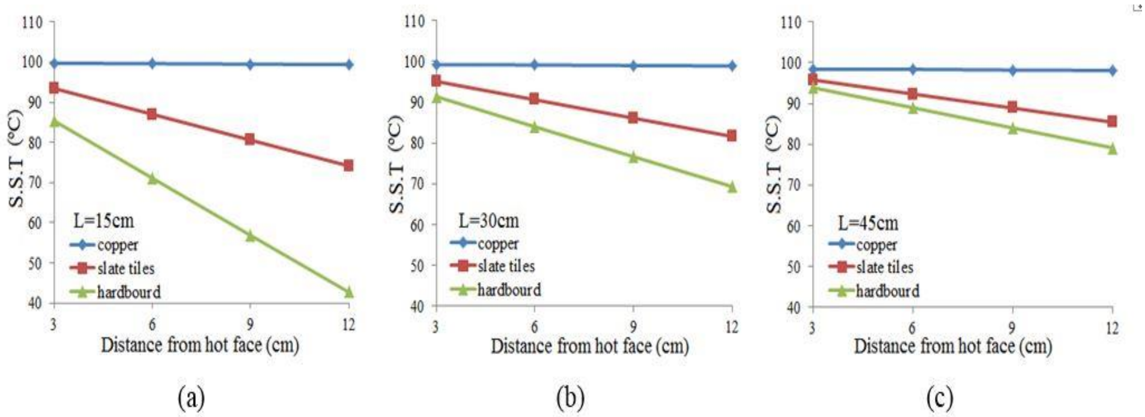


Figure (5) the effect of samples length on temperature of Steady state (S.S.T.)

From the figure (6) we observe that the relationship between the thermal diffusivity (α) and the time required to reach the state of steady is an inverse and takes the form of an exponential relationship where it is obvious that the influence of moving away from the hot face is less than the effect of the sample length on the time required to reach stability.

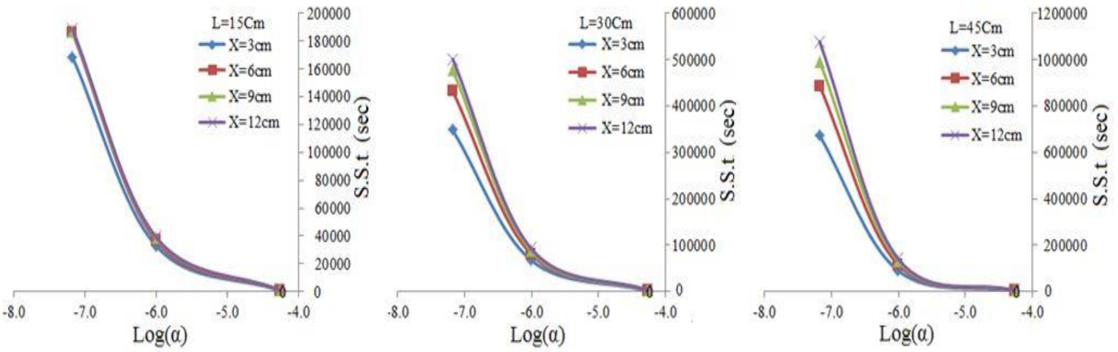


Figure (6) the relationship between log. (α) and Steady state time (S.S.t.)

Figure (7) explains that the temperature of steady state (S.S.T.) will decrease when thermal diffusivity (α) decrease where it is obvious that the influence of moving away from the hot face is less than the effect of the sample length(L) on the temperature of steady state.

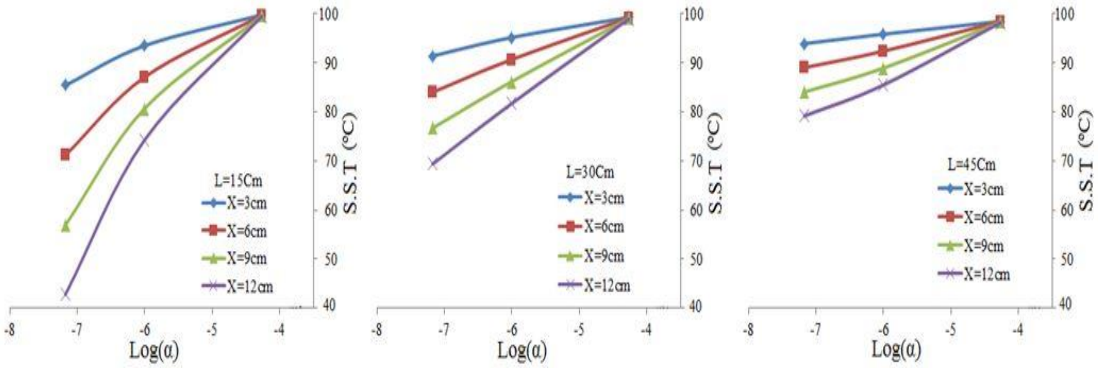


Figure (7) the relationship between log. (α) and Steady state temperature (S.S.T.)

Figure(8) shows the effect of moving away from the hot face at points (x=3,6,9&12) each separately on the time necessary to reach the steady state(S.S.t.) where we note a positive relationship between the distance from the hot face and time to reach the steady state(S.S.t.).

The figure(8) also shows the effect of selected points distance along the sample on the time required to reach the steady state(S.S.t.) for materials have various thermal diffusivity, where we note that there is no effect on the time required to reach the steady state for materials of high thermal diffusivity as the copper. When thermal diffusivity decreases, we note that increasing the length of the sample leads to an increase in time required to achieve the steady state(S.S.t.). This means that increasing the length of the sample will reduce the thermal driving force, which leads to the need for more time to reach the steady state(S.S.t.).

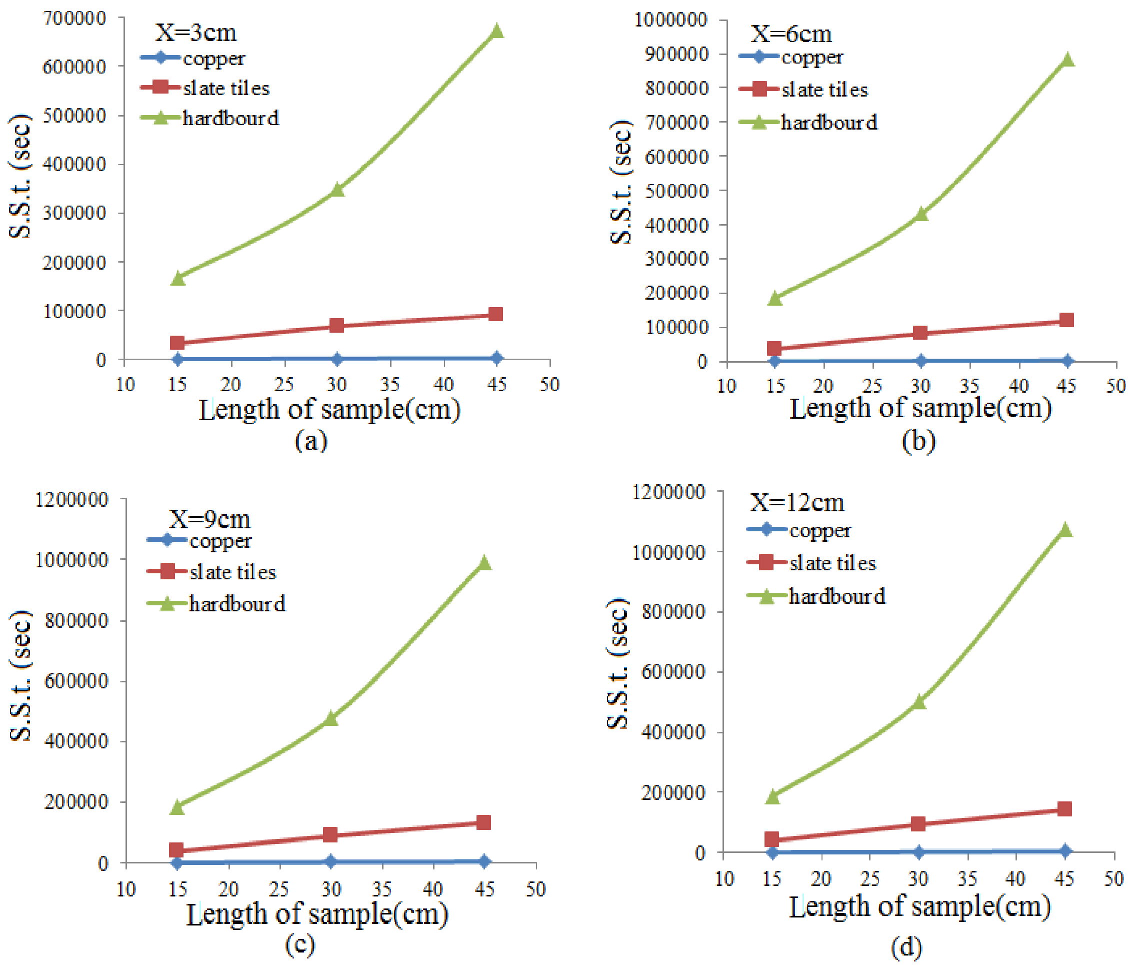


Figure 8(a,b,c&d) Effect of selected points distance on Steady state time (S.S.t.).

4- Conclusions

1- The steady state time increases when increasing the length of the sample, in spite of the fact that the distance from the hot face is constant for all samples and the temperature difference between the sample ends is also constant.

2- The relationship between the length of the sample and the temperature of the steady state is an inverse relation

3- The effect of the distance from the hot face increased in the material that has low thermal diffusivity.

4- At constant sample length, the main variable that effected on the value of S.S.t is the thermal diffusivity.

5- The relationship between the distance from the hot face and the steady state temperature is an inverse relation that takes the form of a straight line, and the straight line slope will decrease when increasing the length of the sample and increasing the thermal diffusivity.

6- The relationship between the thermal diffusivity and the time required to reach the state of steady is an inverse and takes the form of an exponential relationship.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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تاثير طول العينة على الزمن اللازم للوصول الى حالة الاستقرار

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الخلاصة

في هذا البحث استخدم برنامج (ANSYS-14) لدراسة تأثير طول النموذج على الزمن اللازم للوصول الى حالة الاستقرار (S.S.t) لانتقال الحرارة غير المستقرة. تم دراسة ثلاثة نماذج وباطوال مختلفة (15 ،30 و45) سم وبارتفاع 2 سم بالاضافة الى اختيار ثلاثة مواد ذات خواص حرارية مختلفة وتم تطبيقها على الاطوال المختلفة. عرض أحد جوانب النماذج الثلاث الى درجة حرارة مقدارها 100^{o}م، وعرض الجانب الآخر لحمل حراري عند درجة حرارة 25°م وكذلك تم عزل النموذج من السطح العلوي والسطح السفلي. ان الهدف من هذه الدراسة هو لمعرفة مدى تاثر زمن الوصول الى حالة الاستقرار عند تغيير طول النموذج المعرض لحمل حراري ثابت ولمواد مختلفة بالاعتماد على مسافة محدده عن الوجه الساخن لجميع الاطوال عند عدد من النقاط (3 ،6 ،9 و12) سم .من نتائج الزمن الذي تم الحصول عليها عدديا من برنامج ANSYS،اعتمد زمن الوصول الى حالة الاستقرارعندما يكون الفرق بين درجة حرارة النموذج التي وصل اليها مع الدرجة التي قبلها بمقدار 0,001 .اوضحت النتائج ان الزمن اللازم للوصول الى حالة الاستقرار(S.S.t) يزداد بزيادة طول النموذج للنقاط المتناظرة وبثبوت الانتشارية الحرارية (α) حيث كان الزمن اللازم للوصول الى حالة الاستقرار لمادة النحاس يتراوح بين (879−1085) ثانية عند طول 15 سم و(2112−3005) ثانية عند طول 30 سم و(2871−4937) ثانية عند طول 45 سم. كما اظهرت النتائج ان الزمن اللازم للوصول الى حالة الاستقرار يزداد بانخفاض الانتشارية الحرارية حيث كان الزمن اللازم للوصول الى حالة الاستقرار لمادة النحاس ذات الانتشارية الحرارية الاعلى يتراوح بين (4937−879) ثانية لجميع الاطوال بينما كان الزمن اللازم للوصول الى حالة الاستقرار للمادة ذات الانتشارية الواطئة (hardboard) يترواح بين (168400−1078000) ثانية.

الكلمات الدالة: الانتشارية الحلرارية(α)، التحليل غير المستقر، مشاكل التوصيل الحراري، التوصيل الحراري، الطرق العددية لانتقال الحرارة.