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Use of fin analysis for determination of thermal conductivity of material

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Abstract:

The experiment demonstrates the use of fin analysis as one of the possible ways for determination of thermal conductivity of material by using fins. In the experiment the thermal conductivity of unknown material is determined by referring to the standard material of known thermal conductivity. In the experimental set-up, a suitably designed heater coil is used as a heat source. An Aluminium rod is used as reference material and the provision is made in the setup to attach a test rod of which thermal conductivity is to be determined. A Multipole Digital Temperature indicator with seven PT-100 thermocouples are used to measure the temperatures. The geometries of the test and reference rods are mandatory to be exactly same for analysis

Keywords — **Thermal Conductivity, Fin Analysis, Experimental Setup, Infinitely Long Fins**

Introduction:

Thermal conductivity is the ability of material to conduct the heat. It provides the base to differentiate the materials as conductors insulators etc. This differentiation forms one of the bases to select the material for particular application. Hence determination of thermal conductivity is very essential. Various methods have been developed in the recent past for this. These conventional methods are bulky, expensive and require more time to achieve steady state.

In the proposed experimental set-up, Fin Analysis is used as the basis to determine the thermal conductivity of material which overcomes the above mentioned drawbacks. Thermal Conductivity of material is determined relatively by using the material of known thermal conductivity.

1. Different methods to determine thermal conductivity of metals:

Following are the general methods available for determination of thermal conductivity

1.1 Steady-state method : In this method a sample of unknown conductivity is placed between two samples of known conductivity (usually brass plates). The setup is usually vertical with the hot brass plate at the top, the sample in between then the cold brass plate at the bottom. Heat is supplied at the top and made to move downwards to stop any convection within the sample. Measurements are taken after the sample has attained equilibrium (same heat over entire sample), this usually takes about 30 minutes.

1.2 Transient methods The transient techniques perform a measurement during the process of heating up and are quick processes. Transient methods are usually carried out by needle probes. Non steady-state methods to measure the thermal conductivity do not require the signal to obtain a constant value. Instead, the signal is studied as a function of time. The advantages of these methods are that they can in general be performed more quickly, since there is no need to wait for a steady state situation. The disadvantage is that the mathematical analysis of the data is in general more difficult.

1.3 Thermo-reflectance is a method by which the thermal properties of a material can be measured, most importantly thermal conductivity. This method can be applied most notably to thin film materials (up to hundreds of nanometers thick), which have properties that vary greatly when compared to the same materials in bulk. The idea behind this technique is that once a material is heated up, the change in the reflectance of the surface can be utilized to derive the thermal properties. The reflectivity is measured with respect to time, and the data received can be matched to a model which contains coefficients that correspond to thermal properties.

2. Fin Analysis:

Fins are the extended surfaces generally used to enhance the heat transfer rate. Fins are used in many engineering applications to enhance the convective heat transfer rate. Fins are used to enhance convective heat transfer in a wide range of engineering applications, and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area.
For accurate design all real time requirements and constraints are needed. This can be possible by exact assumptions and boundary conditions. Based on such assumptions and boundary conditions following three types can be considered. (For 1-D steady state heat transfer analysis).

Table 1:Temperature distribution & heat transfer rate for 1-D steady state Heat Transfer in fins

CASE	CONDITION	TEMPERATURE DISTRIBUTION	HEAT TRANFER RATE [J/s]
A	Infinitely Long Fin.	$\frac{\theta}{\theta_b} = e^{-mx}$	$\sqrt{hPkA_c\theta_b}$
B	Fin with Insulated Tip.	$\frac{\theta}{\theta_b} = \frac{\cosh m(L-x)}{\cosh mL}$	$\sqrt{hPkA_c\theta_b}\tanh mL$
C	Short Fin.	$\frac{\theta}{\theta_b} = \frac{\cosh m(L-x) + \frac{h}{mk}}{\cosh mL + \frac{h}{mk}}$	$\sqrt{hPkA_c\theta_b}\frac{\sinh mL +}{\cosh mL +}$

Using *Infinitely Long Fin* condition, calculations are quite simplified. In the condition: *Fins with Insulated Tips*, certain amount of heat losses can be expected thereby getting error in the results. All the drawbacks of first and second conditions are overcome in the third condition. The condition: *Short Fin*, gives exact results with infinitesimally small error. But the calculations for short fin analysis are very complicated. Hence, to simplify the calculations infinitely long fin analysis is considered.

3. Assumptions:

- Material used is isotropic in nature.
- Uniform heat transfer coefficient is considered.
- Fins are assumed as infinitely long.
- Steady state analysis is considered.

4. Experimental Set-up:

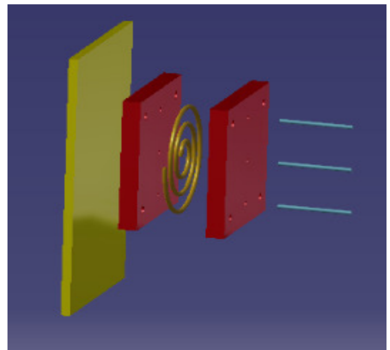
Using the Fin Analysis, Thermal Conductivity is determined in the proposed set-up.
The Set-up is a very concise, portable and light weight. Thermal conductivity of

unknown material is determined using the known thermal conductivity of known material.

The setup is composed of two base plates, three fins, heater coil, a Fe-k temperature sensor, a voltmeter, an ammeter, and a dimmer stat to vary the voltage.

Heater coil is sandwiched between two *Aluminum* base plates of 150[mm] X 100[mm] as Aluminum has constant thermal conductivity over the working temperature range of the experiment. Three fins of Aluminum of 12[mm] diameter and 160[mm] in length are threaded into the upper base plate centrally.

The first and third fin is made of reference material (Aluminum) of known thermal conductivity and the middle one is made of material whose thermal conductivity is to be determined. Thermal sensors are fixed at the fin base and at 100[mm] from the base plate, on each of the three fins to determine fin base temperature and temperature at a distance ‘x’ on fin.
This assembly is enclosed in an acrylic casing to get constant heat transfer coefficient while experimentation as shown in figure 1.a.
By knowing the thermal conductivity of reference material and the temperatures at fin base and fin tip and atmospheric temperature the thermal conductivity of the unknown material can be determined.



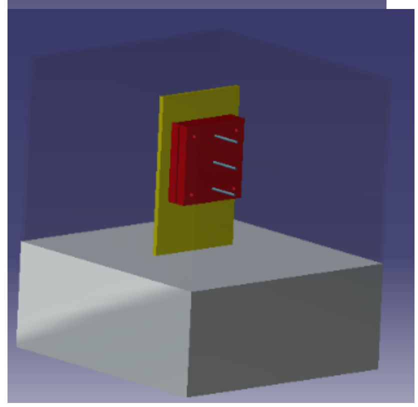


Figure1.a
Figure 1.b

5. Procedure:

- Set constant current and voltage.
- From that heat supplied (Q) = V x I
- Wait till the steady state is achieved i.e. base plate is at constant temperature.
- Note down the temperature readings at respective thermocouples.
- So now we have the base plate temperature, fin base and fin temperature at distance x.
- Calculate thermal conductivity k using formula given below.

6. Formulae:

Temperature distribution for infinitely long fin is
given as -

$$\frac{T_{1X}-T_a}{T_{base}-T_a} = e^{-m_1 x} \qquad \text{.................(1)}$$

$$T_{1X} = \frac{(T_9+T_{11})}{2}$$

Simplifying eq (1) for reference material i.e. Al and for specimen material respectively

$$ln[\frac{T_{1X}-T_a}{T_{base}-T_a}] = -m_1 x \quad \ldots\ldots\ldots\ldots(2)$$

$$T_a = T_{12} \;\&\; T_{base} = \frac{(T_1+T_2+T_3+T_4+T_5)}{5}$$

$$\frac{T_{2X}-T_a}{T_{base}-T_a} = e^{-m_2 x}$$

$$ln[\frac{T_{2X}-T_a}{T_{base}-T_a}] = -m_2 x \quad \ldots\ldots\ldots(3)$$

$$T_{2X} = T_{10}$$

$$\text{Here } m = \sqrt{\frac{hp}{kA}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Rewriting eq (4) as

$$m_1 = \sqrt{\frac{h_1 p_1}{k_1 A_1}} \quad \& \quad m_2 = \sqrt{\frac{h_2 p_2}{k_2 A_2}} \quad \ldots\ldots(5)$$

Subscripts 1 and 2 are used for reference and specimen respectively.
Here h1=h2, p1=p2, A1=A2 can be assumed.

From eq (5)

$$\frac{m_2}{m_1} = \sqrt{\frac{k_1}{k_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Dividing eq (3) by (2) and putting the value of m_1/m_2 from eq (6), we get

$$k_2 = k1[\frac{ln(\frac{T_{2X}-T_a}{T_{base}-T_a})}{ln(\frac{T_{1X}-T_a}{T_{base}-T_a})}]^2$$

By putting the value of k_1 i.e. thermal conductivity of reference material and other values from observation, we can calculate the value of k_2 i.e. thermal conductivity of specimen.

Where,

1. k_1 & k_2: Thermal conductivities of known and unknown material respectively.
2. T_{base}: Temperature of fin base
3. T_{1x}: Temperature of reference at a 'x' distance.
4. T_{2x}: Temperature of specimen at a 'x' distance

7. Limitations:

- Heat transfer coefficient is assumed to be constant for surrounding air.
- The value of thermal conductivity for reference material is taken as constant value. In fact thermal conductivity of material varies with working temperature.

8. Result and Conclusion

Comparative analysis under identical surrounding and geometrical constraints provides minimum error. The setup offers flexibility to test different metals on same setup. Experimental setup is designed to minimize the contact resistance. No insulation is required and specimen size is small which makes the setup compact and portable. Specimens required are easy to manufacture. Power source and temperature sensors are the only instrumentation required. The setup can be used in technical institutes for experimental purpose for the determination of thermal conductivity.

9. Future Scope:

- To develop a program to calculate the thermal conductivity of material by accepting the temperature readings and thermal conductivity of reference material as input values to make the setup more user friendly.
- The purpose of this project is also to develop a test set up to cater to academic need. This will also

make available an opportunity to go for start-up. These set ups can be made available to other Engineering colleges as academic setups.

10. References:

[1] Y.A. Cengel, Heat and Mass Transfer, Tata McGraw Hills publications, Fifth Edition

[2] https://www.researchgate.net

[3] Thermal conductivity- Different method to find thermal conductivity of material. URL: http://www.azom.com/article.aspx?ArticleID=5615

[4] Heat transfer from fin e-learn URL: http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node128.html

[5] Ramesh S. Goankar, "Microprocessor Architecture, Programming and Applications with 8085" 5th Edition.