Memorandum

Date: November 21, 1999
To: Doug Cairns
From: Laurence Magone
RE: Thermal Properties Laboratory

Purpose

The purpose of the thermal expansion and heat transfer laboratory was to observe the impact of temperature on material dimensions and observe the three modes of heat transfer. In addition to observations, the laboratory intended to obtain numerical results for both heat transfer and thermal expansion.

Procedure

The procedure for the thermal expansion laboratory was very straight forward. The material sample to be tested was placed on the heater and the precision displacement gauge was placed on the sample. The dial was zeroed out. Next, the heater was turned on and the material began to expand. At regular intervals (1/1000th inch increments), the time and temperature of the sample was recorded. The laboratory ended when the thermal expansion rate approached zero.

The procedure for the heat transfer laboratory was divided into three sections: transient heat conduction, thermal conductivity, and specific heat.

Transient Heat Conduction

1. Place each of the samples on a hot plate.
2. Turn on the hot plate and allow it to reach the temperature already set by the lab assistant.
3. Record the bottom temperature of the steel sample on fifteen second intervals. Record these values in the table provided.
4. Continue recording data until system has reached steady state.
5. Record the upper and lower thermocouple temperature for all samples.
6. Cool the plastic sample by submersing and agitating in the water bath.
7. Dry off the plastic sample.

Thermal Conductivity

1. Place the plastic sample on top of the steel sample.
2. Allow the plastic sample to reach steady state. Record the upper and lower thermocouple temperatures of the plastic sample.

Specific Heat

1. Fill the Thermos to the desired level that is marked on the line on the inside of the container.
2. Record the temperature of the water in the insulated Thermos.
3. Remove the aluminum sample and place it in the insulated known quantity of water. Turn off the hot plate.
4. Close the insulated container by placing the rubber stopper on top. Allow the temperature of the system to reach steady state.
5. Record the final temperature of the water and aluminum sample.

Results

The plastic sample took a great deal of time to heat up to the prescribe temperature. Sixty minutes of continuous heating were required to heat the plastic sample to the prescribed temperature. The experiment took far less time to cool the sample off using room temperature water. Two hundred and ten seconds were required to cool the sample off.

This difference in time can be explained by the method of heating and cooling. Heating the plastic sample was done entirely by heat transfer using just one side of the plastic sample. When the sample was cooled down, all three sides were used in transferring the heat from the plastic to the water. The additional two sides greatly increased the surface area used in cooling and this resulted in a cooling time that was decreased by several magnitudes.

Procedure used to obtain results

Few equations and graphs were used to obtain the results of the thermal expansion laboratory. To calculate **a**, the linear coefficient of thermal expansion, the equation $a = \frac{1}{\Delta T} \bullet \frac{d_T}{L_0}$ was used, where **d**$_t$ = change in length, **D**T = change in temperature, and L_0 = original length. This equation is only valid when the material sample is free to expand and is not laterally constrained. Additionally, **a** is constant only when the changes in temperature (**D**T) is less than 10°F.

To solve the hypothetical problem presented during the experiment, the equation $e = \frac{s}{E} + a(\Delta T)$ was used, where **s** = stress, E =elastic modulus (29x10^6), **a**=12 x10^{-6} °C^{-1} (equation given above), and **D**T = 40°.

Two equations were used to compute the results of the heat transfer laboratory. To solve for thermal conductivity of the plastic (k2), the equation $\frac{k1 \cdot \Delta T1}{\Delta X1} = \frac{k2 \cdot \Delta T2}{\Delta X2}$ was used, where k1 = 60.5; ΔT1 = 1°F; ΔX1 = 1.25 inches; ΔT2 = 56°F; and ΔX2 is 1.25 inches.

To calculate the heat capacitance of the aluminum sample, the equation $M_w \cdot C_w \cdot \Delta T_w = M_{AL} \cdot C_{AL} \cdot \Delta T_{AL}$ was used, where M_w =400 g; C_w = 4.184 J/g·K; and ΔT_w = 11.5°; M_{AL} = 358 g; and ΔT_{AL} = 61.9°.

Numerical Results

a, the coefficient of thermal expansion, was between 11 x 10^{-6} °C^{-1} and 15.5 x 10^{-6} °C^{-1} for changes in temperature less than between 10° and 20°F. This number is consistent with book values of 12 x 10^{-6} °C^{-1}.

The answer to the hypothetical problem presented in class is 13,920 pounds of force.

The thermal conductivity of plastic is 1.1 W/m·K. This is considerably different than the book value of ≈ .25 W/m·K. Please see the next section for an explanation for the difference.

The heat capacitance of aluminum is 868 J/kg·K. This number is comparable to the book value of 900 J/kg·K

Interpretation of Results

Sources of Error

The thermal expansion laboratory experiment was more erroneous than laboratories in the past. It was quite a bit more difficult to ensure accurate results. When setting up the experiment, the displacement gauge was zeroed by moving the gauge across the piece of steel until the dial read zero. The displacement gauge was not as securely immobilized as it should have been because a small bump would change the reading by two or three thousandths of an inch.

The vertical bar used to measure the displacement was not resting perpendicular to the sample, instead, it was off perpendicular by a few degrees. This induced inaccuracies because the gauge is only accurate when the bar rests perpendicular to the sample being tested.

Finally, this lab allows for a large degree of human error. No part of the lab is automated. After the bar has extended by a thousands inch (decided on by looking at the dial gauge), the temperature and the elapsed time are recorded. All three activities—deciding when to record values, recording the temperature, and recording the elasped time—are subject to human error. Since the temperature increases quite rapidly, there was possibility of recording the incorrect temperature at the given extension.

The heat transfer laboratory should have been accurate. The main source of error is because it is assumed that the heat transfer occurs in a closed system where no heat transfer occurs outside of the container. Since the experiment was conducted in the real world, the system was not closed and some heat was transferred to the outside world. This loss should have been minimal.

Graphical Results

Figure 1 represents the temperature versus time graph for the steel sample. It shows that the steel rapidly increased temperature at first and gradually increased temperature toward the end of the experiment.

Figure 2, although not required for the memorandum, is interesting. This graph shows temperature vs. amount of extension. The amount of extension increases in a logarithmic fashion. The greatest rate of expansion is when the material sample is close to room temperature and the lowest rate of expansion is when the sample is around 400℉.

Figure 3 represents the thermal strain as compared to **D**T. The slope of the linear portion, that is, the slope between points (0.0011,1) and (0.0025,10), is equal to a. The equation on the graph is the equation of the curve fitting line for this portion of the graph.

Conclusion

Practical Applications of Data

Thermal expansion is one of the most important mechanical properties to consider in the design of a product. All mechanical devices change temperature during use and that change in temperature can have an important impact on product performance. Two different materials usually expand and contract at different rates. Brittle fracture, increased stress, and additional strain all can be a result of poor choice of materials.

More specifically, the steel sample tested in the laboratory expanded 34/1000ths of an inch when the temperature was increased from 65℉ to 429℉. If the sample was not able to expand, it would put a force of 13,920 pounds on whatever was preventing it from expanding. There are few situations that would resist this tremendous force. Most situations would fracture and then allow the steel to expand.

This situation would not normally occur, however. Since all steels of the same composition expand at the same rate, most often the expansion is not a factor. The primary issue is when two different materials are used in the design of a structure. Dissimilar materials have dissimilar coefficients of expansion and therefore expand at different rates. This is not always an issue, for example, often times thermostats make use of these properties. By physically joining two different metals, one will expand at a different rate and trigger the thermostat at a given temperature.

The ability to transfer heat is also an important property of materials to consider in the design of a product. Certain materials work well as thermal insulators and other materials act well as thermal conductors. Since high temperatures can often degrade the performance of materials or cause potential fire hazards. If a heat source is contained in a product, it is essential to calculate the amount of heat the source will generate and the amount of heat the materials used in the product will dissipate the heat. Using thermodynamic equations and the results found in the laboratory will allow an engineer to ensure the product will work as intended.

Conclusions about Steel Sample Tested

The steel sample tested increased length by 34/1000 of an inch or about 0.66% of the total sample length. 0.5% is a small amount and would not be noticed in most smaller applications, as the tolerance would sufficiently absorb most changes in length. For large applications, however, the extension value becomes an issue. One steel bar, for example, in North Hedges was formed by welding several sections of tubing together. The entire steel bar runs from the top of the building to the bottom and is about 120 feet long. This bar would expand by 9.5 inches if it was subjected to this change in temperature. Several design modifications are necessary to prevent the steel bar from warping or damaging the components it is attached to. A second example is commonly seen in long bridges. Because of the length (oftentimes several hundred or thousand feet), the steel expansion caused by the hot sun would cause the bridge to fail after a few year. The solution is to use several expansion gaps that allow the bridge to expand and contract during temperature changes.

Conclusions about the Aluminum and Plastic Samples tested

Plastic makes an effective thermal insulator. The value of thermal conductivity of plastic was much smaller than the value of thermal conductivity for aluminum. The heat capacity, however, of aluminum is very small. Water requires approximately 4184 joules to heat one gram one degree while aluminum only requires approximately 900 joules to heat one gram one degree. Aluminum would work well in situations where rapid heat changes are a necessity but would not work well in situations where it was beneficial to store heat. Wood stoves and cookware are two examples of where it is beneficial to store large amount of heat, and therefore, are not made out of aluminum.