THERMAL CONDUCTIVITIES PARALLEL AND PERPENDICULAR TO NYLON'S EXTRUSION AXIS

Louis J. Dorland
Physics Department
South Dakota School of Mines and Technology
Rapid City, South Dakota 57701

ABSTRACT

Ashworth, et. al.[1] suggest that the thermal conductivity of nylon is a function of heat-flow direction. This paper investigates the thermal conductivity of Comco brand Nylon 66 (polyhexamethylene adiapamide). Heat-flow is both parallel and perpendicular to the axis of extrusion.

The data is from an unguarded plate apparatus which has been described by Lacey[2]. The temperature range is 20C to 80C.

The following areas are discussed: (1) the apparatus used, (2) the thermal conductivity of nylon, (3) experimental errors, and (4) optimizing modifications to the apparatus.

The thermal conductivity of nylon is found to be a function of heat-flow direction.

INTRODUCTION

Subject

Nylon is a hydrocarbon. A molecule of nylon is built around a long chain of carbon atoms. Nylon is formed under an anisotropic stress called extrusion. This stress tends to align the long molecules parallel to each other. This alignment is parallel to the extrusion axis. Since heat conduction in a material is intimately connected to the molecular structure, nylon should show an anisotropic thermal conductivity.

Purpose

This paper investigates a hypothesis set forth in "Use of Linear Heat Flow for Poor Conductors and Its Application to the Thermal Conductivity of Nylon"[1]: that the reason for the differences between their data and D. E. Kline's data[3] is due to heat-flow directions. Furthermore, this paper investigates the sources of experimental errors in the data, as well as modifications to the apparatus.

Plan of Development

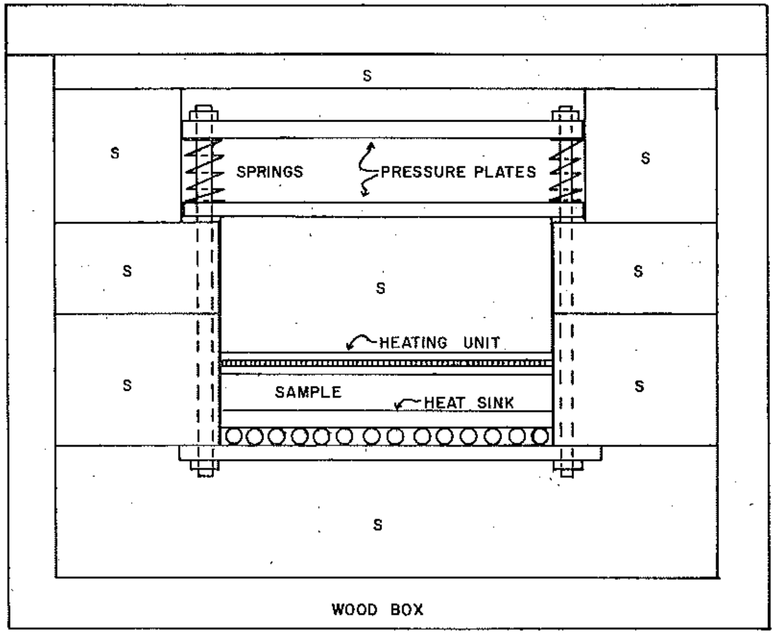
This paper is divided into three main parts: (1) the apparatus used, (2) the thermal conductivity of nylon, and (3) optimizing modifications to the apparatus.

THE APPARATUS

Description

The thermal conductivity apparatus is an unguarded plate system as described by W. G. Lacey in his M. S. Thesis[2]. The design is simple and straightforward as illustrated in Fig. 1. The sample is a disk 12.7 cm in diameter and 1.27 cm thick. On one face of it is a heat sink that can be kept at a constant temperature. The heat sink is a disk of copper 12.7 cm in diameter and 0.64 cm thick. A copper pipe 0.48 cm in diameter is sweat soldered to the bottom of the disk in a spiral manner and water is pumped through it. A Neslab Controlled Temperature Bath is used to keep the heat sink at the desired temperature.

The heater is made from two disks of copper the same diameter as the heat sink but each only half as thick. Several meters of high resistance insulated wire are uniformly laid between the disks which are then sealed together. When current is passed through the resistance wire heat is uniformly generated across the face of the sample.



S = STYROFOAM INSULATION

Figure 1. The apparatus

Pressure applied to the sample assembly insures good thermal contact. The sample assembly is surrounded by styrofoam which has a low thermal conductivity. Therefore, most of the heat generated in the heater flows through the sample; however, some heat flows through the insulation, and corrections must be made for these heat losses.[4]

Monitoring Setup

A potentiometer (see figure 2) is used to measure the voltage drop across a standard resistor placed in series with the heater enabling the current (I) flowing through the heater to be found. The voltage drop (V) across the heater is found by using a potential divider placed in parallel with the heater. The power (P) dissipated in the heater is calculated from $P = IV$.

Two sets of copper-constantan thermocouples are used to monitor the temperatures of the heater and the heat sink. One thermocouple junction is placed in the center of the heater (on the sample side), and the other junction is referenced to a thermometer outside the sample chamber. The thermometer is placed in good thermal contact with a one kilogram block of brass.

The other set of thermocouples is placed across the center of the sample. This gives the temperature gradient between the two faces of the sample disk, and indirectly the temperature of the heat sink.

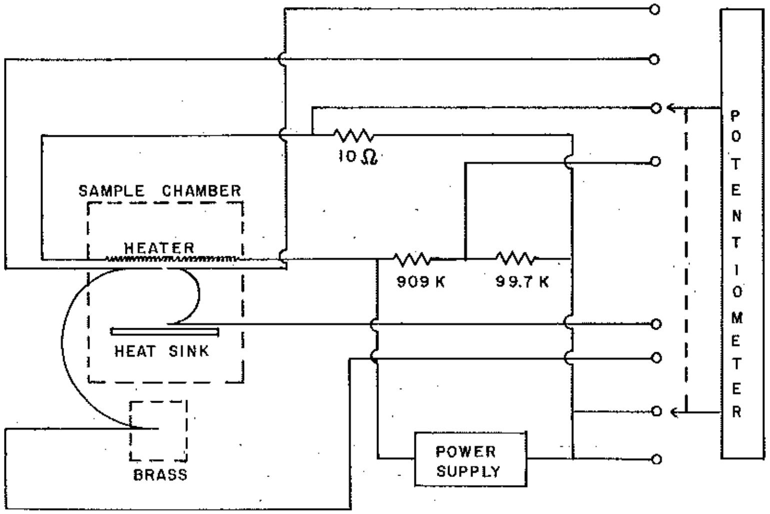


Figure 2. The measurement circuit

A data point for this apparatus consists of the following parameters:

(1) The voltage produced by the thermocouple between the heater and the thermometer.

(2) The voltage produced by thermocouple across the sample.

(3) The voltage drop across the heater.

(4) The voltage drop across the standard resistor.

(5) The mercury thermometer at the reference junction.

(6) A mercury thermometer by the standard resistor and potential divider network.

Due to fluctuations in the thermocouple voltages several data points are taken over a period of one hour. In this manner an average data point is obtained. Spurious voltages are generated in the thermocouples due to a junction box outside the sample chamber. These are eliminated by taking three average data points: (1) one with no power generated in the heater, (2) one with enough power generated to produce a temperature gradient of one degree across the sample, and (3) one where the temperature gradient is two degrees. From this data a plot is obtained of power generated in the heater vs. temperature gradient across the sample. The slope is unaffected by the spurious voltages since these affect only the intercepts of this curve. The slope is then used to calculate the thermal conductivity of the sample.

THERMAL CONDUCTIVITY OF NYLON

Sample

The samples are two cylinders of Nylon 66. Each is 1.92 cm in diameter and 1.34 cm high. One cylinder's axis is parallel to the extrusion axis. The other cylinder's axis is perpendicular to the extrusion axis. These samples fit into a guard ring 12.7 cm in diameter and 1.34 cm thick. A hole 1.92 cm in diameter is milled through the guard ring's center. The disk's axis is perpendicular to the extrusion axis. The sample and guard ring is of dimensions suitable for the apparatus used.

Data

The data is illustrated in Graph 1. The heat-flow is parallel to the extrusion axis for the Z's and perpendicular for the X's. Graph 1 is not corrected for heat losses[4]. However, since the correction factor is a constant over this temperature range, the form of the curve is unaffected. The corrected values are in Tables 1 and 2.

TABLE 1

Heat-Flow Perpendicular To Extrusion Axis
Thermal Conductivity of Nylon 66
Watts/(Meter-Kelvin)

Temp °C	Uncorrected For Heat Loss	Corrected For Heat Loss
21	.3030	.3005
35	.2955	.2931
49	.3055	.3029
63	.3139	.3113
77	.3152	.3126

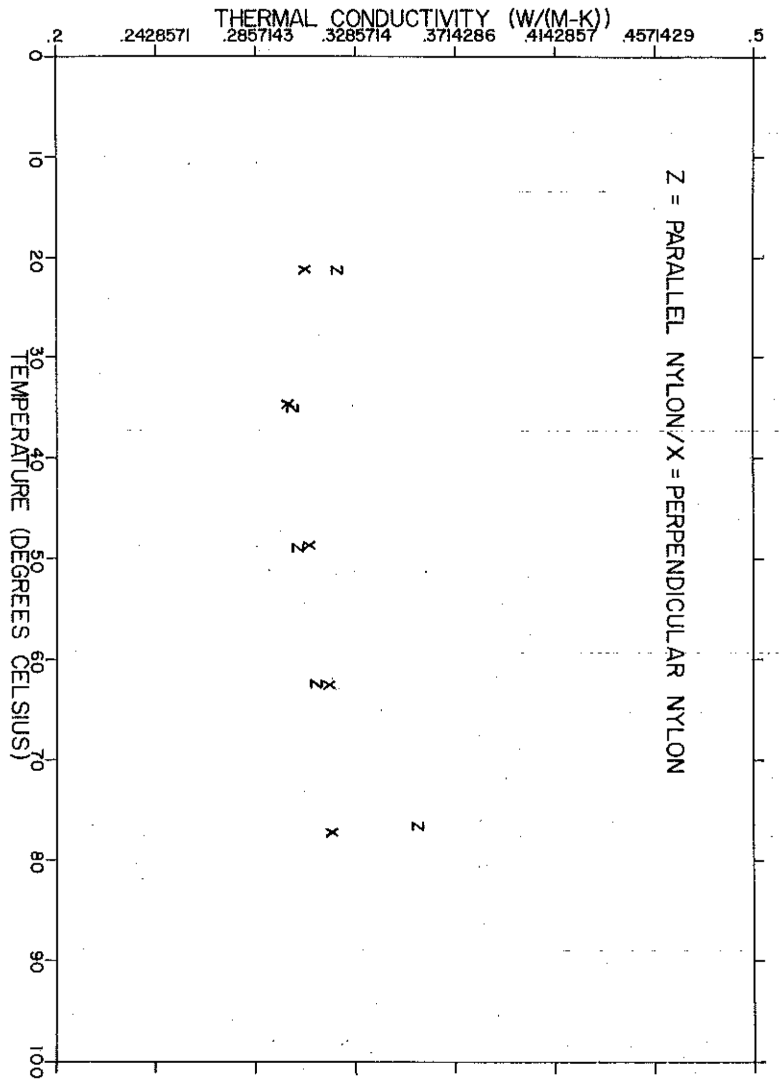
TABLE 2

Heat-Flow Parallel To Extrusion Axis
Thermal Conductivity of Nylon 66
Watts/(Meter-Kelvin)

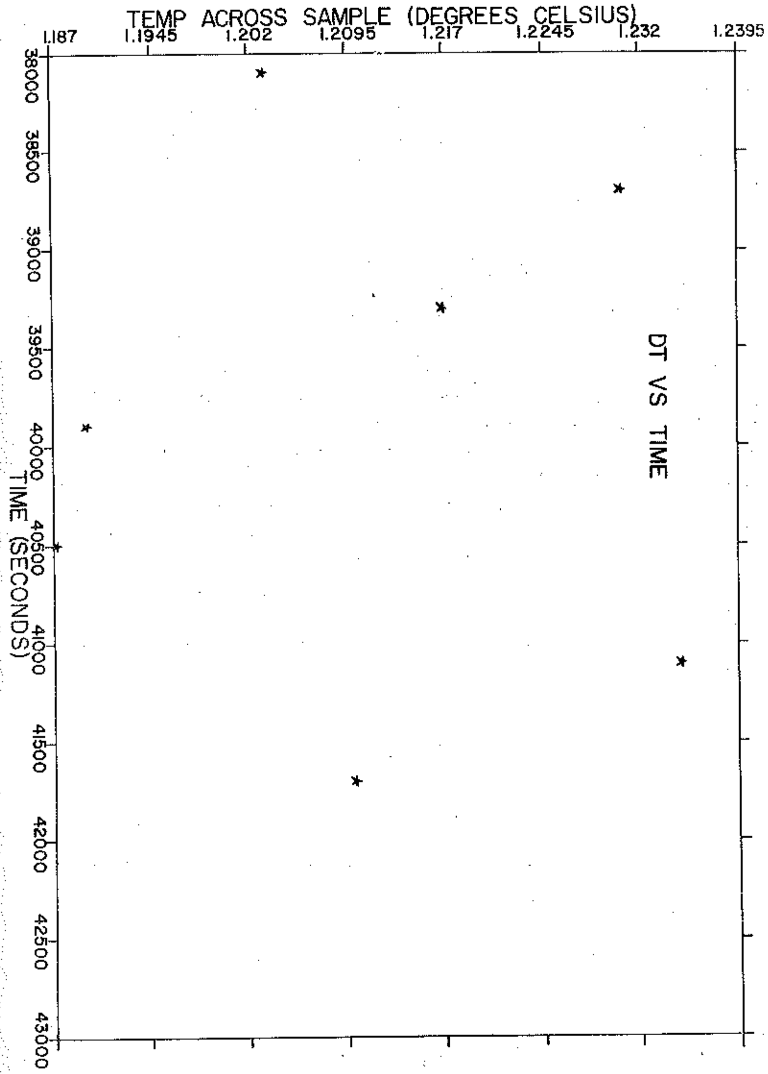
Temp °C	Uncorrected For Heat Loss	Corrected For Heat Loss
21	.3167	.3141
35	.2974	.2949
49	.2995	.2971
62	.3085	.3060
77	.3508	.3479

W. G. Lacey reports[3] the accuracy of the apparatus to be 6%. Except for the points at 77C and 21C, the two sets of data are within 3% of each other. Thus, a definite conclusion cannot be drawn. However, the points at 77C and 21C indicate that there is indeed a dependence on heat-flow direction for nylon's thermal conductivity.

It is clear that the apparatus should be made more accurate in order to resolve the differences in the thermal conductivities of nylon. This is discussed in the next section.



Graph 1



Graph 2

MODIFICATIONS TO THE APPARATUS

The majority of the errors involved in using this apparatus are absolute errors; i.e., the precision to which the sample thickness and heater plate area are measured. It quickly becomes quite expensive to improve these errors. However, it would improve the relative accuracy of the apparatus tremendously if the fluctuations in the thermocouple voltages could be reduced (see section on Monitoring Setup).

Graph 2 is a plot of the temperature gradient across the sample vs. time. The temperature gradient is the main parameter used in calculating the thermal conductivity of a sample. The graph indicates that the temperature gradient across the sample fluctuates erratically. These fluctuations may be caused by three things: (1) fluctuations in the power dissipated in the heater, (2) fluctuations in the temperature of the heat sink, and (3) spurious voltages generated in the thermocouple circuit. If the first two are the probable sources of the errors, then graph 2 would be more continuous. Since the thermocouple circuits have solder joints outside the sample chamber, these would also act as thermocouple junctions. Any temperature changes at these solder joints would altar the voltage in the circuit. These solder joints are enclosed in metal junction boxes. Air currents over these boxes are the probable source of temperature fluctuations. Therefore, these boxes should be insulated from any air currents and other quick changes in temperature.

CONCLUSION

Summary

This paper has discussed the following: (1) the apparatus used, (2) the thermal conductivity of nylon, and (3) suggested modifications to the apparatus.

Recommendations

In view of the areas discussed in this paper the following recommendations are made:

(1) all the junction boxes for the thermocouple wiring should be insulated from air currents and fast temperature fluctuations, and

(2) this data should be retaken so as to show reproducibility.

Closing Comment

In conclusion, from the data it seems apparent that the thermal conductivity of Nylon 66 is indeed a function of the heat-flow direction.

REFERENCES

1. Ashworth, T., L. R. Johnson, C. Y. Hsiung, and M. M. Kreitman 1973. Use of the Linear Heat Flow for Poor Conductors and Its Application to the Thermal Conductivity of Nylon, Cryogenics 13:34.
2. Lacey, W. G. 1975. M.S. Thesis, South Dakota School of Mines and Technology, Rapid City, S. D.
3. Kline, D. E. 1961. Journal of Polymer Science, 50:441.
4. Ashworth, E. 1976. Report for Mining 611.