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Thermal Properties of Automotive Polymers
II-Thermal Conductivity of Parts Selected From a Dodge Caravan

Reported By
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Abstract

A new method has been developed for measuring the thermal conductivity of polymeric materials. The method is based on heat capacity measurements made using modulated differential scanning calorimetry (MDSC). This technique is capable of quantitatively separating reversible (heat capacity related) thermal events from nonreversible thermal events. The advantages of the method are that it is fast and leads to accurate thermal conductivity measurements.

The new method was used to measure thermal conductivity of standard polymers and 43 polymeric parts used on a 1996 Dodge Caravan. The results show that crystalline polymers have higher thermal conductivity than amorphous polymers. For any one polymer, thermal conductivity increases with an increase in filler concentration. In the case of polymeric foams and other insulating materials, the density of the foam has the major effect on the value of thermal conductivity, although other variables, such as the foam cell size and geometry, and the type and amount of polymer and filler used for making the foam, need to be considered. In the temperature range between glass transition and melting, thermal conductivity decreases as temperature goes up. Measured thermal conductivity values will be used for calculating materials constants for ignition and combustion.

Purpose

This report describes work being done under the “flammability of materials” project, which is part of the fire safety research program of the March 1995 General Motors/U.S. Department of Transportation Settlement Agreement. The overall objective is to study the flammability properties of materials used in vehicle interiors and exteriors. For selected materials, efforts will be made to identify or devise cost effective, less flammable substitutes which will not compromise other important physical properties.

The purpose of this part of the investigation is to determine the thermal conductivity of polymeric materials used in vehicles and use this data to calculate materials flammability constants.

Conclusions

An accurate and fast method for measuring thermal conductivity has been developed. It was used to measure the conductivity of polymeric parts used on passenger vehicles. Thermal conductivity values are used to calculate material flammability characteristics.

Significance

The information developed in this study can be used to quantify the flammability of polymer compositions and can help to identify less flammable substitutes.

Introduction

This is the second report on thermal properties of polymers used in vehicles. The first report dealt with thermal gravimetric analysis (TGA) and differential scanning calorimetry (DSC) of polymeric composites taken from a Dodge Caravan **[1].** This report describes thermal conductivity measurements performed on the same parts.

A new technique will be described based on modulated DSC. The advantages of this technique is that it is less laborious and requires less time to conduct than conventional techniques used for thermal conductivity measurements **[2].** A detailed description of this technique will be presented in the discussion section of this report.

Experimental

Materials: Thermal conductivity measurements were carried out on polymeric compositions taken from parts of a 1996 Dodge Caravan. These compositions were all described in a previous report [**1].** Table I of that report gives a summary of the parts investigated along with the identification of the types of polymer used in making these parts and the type and amount of filler they each contain. As seen from the table, the parts included: headliner, instrument panel, toe pan parts, heating and air conditioning parts including air ducts, brake fluid reservoir, fender, hoodliner, fuel tank, headlight, battery, wheel well, weatherstrip, and bulkhead insulation.

Apparatus: The apparatus used for this study is the modulated DSC manufactured by TA Instruments (MDSC 2920). The technique is relatively new. Conventional DSC is a device for measuring the heat flow into and out of a sample as it is being heated isothermally or in a linearly rising temperature program. From these measurements, thermodynamic properties of materials, such as, heat capacity, melting points, heats of fusion, and glass transition temperatures, are quantified. Modulated DSC uses a constant heat input rate along with a small modulated rate. The modulation is achieved by imposing a sine wave input on the underlying constant rate. Applying Fourier transform analysis on the output signal from the MDSC one is able to discern between thermodynamic reversible changes and nonreversible kinetic changes as the polymer is being heated [7]. The reversing heat flow is used as a direct measurement for heat capacity. This is of primary interest to the work in this report since heat capacity and thermal conductivity are related properties.

Procedure: For the determination of thermal conductivity, both specific heat of a thin specimen (<0.5 mm) and apparent heat capacity of a thick specimen (> 3.0 mm) are measured. Uniform specimens were cut from appropriate areas of polymeric parts from the Dodge Caravan using a cylindrical cutter, 6.35 mm in diameter, to obtain the required thin and thick samples. If only thick samples were available, the thin samples were obtained by shaving down to the desired thickness. If the part was thin in all areas, thick samples were prepared by compression molding of shavings, taken from the part, to the proper thickness. In all cases, uniform samples with parallel surfaces were prepared in order to assure proper precision of the thermal conductivity measurement.

The Modulated DSC (MDSC) was calibrated using indium metal and sapphire as reference materials. Thermal conductivity calibration was performed using polystyrene samples as a reference material.

Specific heat and heat capacity measurements were conducted using standard MDSC procedures. The heating rate was 5°C/minute, and the degree of modulation was 0.5°C within a period of 80 seconds. For apparent heat capacity determinations, the length and diameter of the samples were measured in addition to the mass. For improving precision in both measurement and insuring proper contact between the sample and the thermocouples on the measurement platform, aluminum foil disks wetted on both sides with highly conductive silicone oil were placed between the DSC specimen and the platform. An equivalent foil disk with silicone oil is used on the reference platform of the cell. The specific heat and the apparent heat capacity values, thus determined, are used to calculate thermal conductivity.

Results & Discussion

Thermal Conductivity Measurements Method:

Thermal conductivity is defined by the following equation:

$$k = (Q/A).(x_2-x_1)/(T_2-T_1) \qquad (1)$$

Q is the power across the specimen cross-sectional area A. T_2 and T_1 are the temperatures at points x_2 and x_1, lying normally across the thickness of the specimen. Before accurate thermal conductivity values can be obtained, three conditions must be met [2-4]: (1) The power Q across the sample thickness should be known. The amount of power given by an electric heater, normally used for the measurement, is easily calculated, but problems arise in accounting for heat loss and determining the power used up by the sample only to cause the temperature gradient. (2) The temperatures T_2 and T_1 at the points x_2 and x_1 are known. Thermal conductivity measurements are often made across the thickness of the sample. For accurate measurements, the thermocouples have to be perfectly mated with the sample surfaces using a highly conductive adhesive such as a conductive silicone grease. However, for many samples, it is difficult to attain good contact. The resulting high contact resistance can produce an erroneous low measured thermal conductivity value. (3) Heat flow should be unidirectional, and heat losses in directions across the desired heat flow should be minimized. For polymers, either a slab with parallel faces or a circular cylinder are used. The smallest thickness that gives an accurately measured AT should be used.

Experimentally, methods of measuring thermal conductivity are designed with guard heaters, insulation materials, and heat sinks arranged strategically around the specimen to minimize heat losses **[2].**

By addressing all these issues, the measurement of thermal conductivity by conventional methods becomes time consuming and still involves considerable experimental uncertainty. For example, a comparison of measured values of thermal conductivity of tungsten by 15 independent laboratories using various direct heating techniques exhibited differences in the order of 50% at lower temperatures and up to 100% at higher temperatures **[2].** Also, the change in thermal conductivity values with temperature have been found to be smoothly increasing and smoothly decreasing for the same material and within the same temperature range **[5].** A similar scatter is also observed for the variation in the values of experimentally measured thermal conductivities of polymers.

The methods for measuring the conductivity of polymer parts taken from the Dodge Caravan is based on a technique that employs a modulated differential scanning calorimeter (MDSC). The technique allows the measurement of heat flow into and out of a sample. The signal value at any temperature is dependent on the value of the temperature as well as heating rate.

$$dQ/dt = C_p(dT/dt) + f(t,T) \qquad (2)$$

Q is the amount of heat absorbed or given out. Its value is determined by the thermodynamic heat capacity (C,) which is a measure of the reversible heat exchanged by molecular motions and by kinetic absorption of heat due to non-reversible physical or chemical changes occurring at a specific temperature(T) and time(t), [f(t,T)].

In MDSC, a constant heat input rate is used along with a small modulated rate. The modulation is achieved by imposing a sine wave input on the underlying constant rate. Heat rate input for the MDSC is schematically shown in Figure 1 **[6].** Raw data from a MDSC experiment on quenched polyethylene terephthalate (PET) is shown in Figure 2. Applying Fourier transform analysis on the output signal of the MDSC, one is able to discern between thermodynamic reversible changes and nonreversible changes as the polymer is being heated. This is demonstrated in Figure 3, showing the total heat flow, the reversible heat flow attributable to changes in heat capacity at the glass transition and the nonreversible heat flow arising from a relaxation endotherm of a polypropylene sample.

The best heat capacity results are obtained when experimental conditions are selected to obtain maximum temperature uniformity across the test specimen. Small thin specimens and long oscillation periods produce the best results. When test conditions lie outside these guidelines, the accuracy of specific heat values declines due to low thermal conductivity of the sample preventing uniform temperature conditions across the test specimen. Alternatively, the effect of thermal conductivity is enhanced by the use of thick specimens and the use of open pans which allows the application of temperature oscillation to only one side of the sample. For low conductivity samples, the apparent heat capacity values in an open pan were measured at less than half the value of an encapsulated sample [6]. The one-dimensional heat flow model of a low conductivity material using the modulated heat flow of the MDSC yields the following relationship [6]:

$$K = (2\,(2\pi \,.C^2) / (C_p .\, \rho \,.\, A^2 \,.\, P) \qquad (3)$$

Where :

K = Thermal conductivity (W /°C cm)
C = Apparent heat capacity (J/°C) = (dQ/dt) / (ω.To) and $\omega = 2\pi$ / Period (P)
C_p = Sample specific heat (J/°C g)
ρ = Sample density (g/cm^3)
A = Sample cross sectional area (cm^2)

For circular samples where ρ = M/AL and A = π . d^2) / 4, the above equation becomes:

$$K = (8L \,.\, C^2) / (Cp \,.\, M.\, d^2 \,.\, P) \qquad (4)$$

L, d, and M are the sample length(height), diameter and mass, respectively.

MDSC results of the thermal conductivity of standard polymers using the methodology described above and equation 4 to calculate the values showed that they were higher than the literature values by about 21%. This was attributed to the loss of thermal energy through the sides of the test specimen. A calibration constant (D) has to be used to correct for this effect. D is defined by the following equation:

$$D = (K_o \,.K_r)^{0.5} - K^r \qquad (5)$$

Where K_o is the observed reference material thermal conductivity and Kr is the true thermal conductivity. For a 6.35 mm diameter test specimen, the value for D is typically 0.014 W/°C m. The corrected thermal conductivity of a sample can be calculated by substituting this value of D in a rearranged form of equation 5 shown below (equation 6).

$$K = [K_o - 2D + (K_o^{\,2} - 4DK_o)^{0.5}]/2 \qquad (6)$$

With this correction factor, values of thermal conductivity of polymers measured by the MDSC technique are within 3% variation of literature values. Because of assumptions and experimental limitations, Marcus and Blaine [6] state that the technique is usable for the measurement of thermal conductivity of insulating materials in the range of 0.1 to 2 W/(m-°C).

Measurement Verification:

To verify the validity of the method outlined in the experimental section for measuring thermal conductivity using MDSC, we conducted two series of experiments using samples taken from a polypropylene battery cover. The results are shown in Table I. For a one-piece polypropylene cylindrical sample with the right dimensions, the thermal conductivity was measured to be 0.226 +/- 0.008 standard deviation. This is within the 3% variation expected of this technique. However, if samples are not carefully prepared, different thermal conductivity results are obtained, as seen in Table I. If the sample is below the recommended thickness, lower thermal conductivity values of 0.176 W/m-°C are measured. Similarly, lower values of thermal conductivity are measured for stacked pieces (0.186 W/m-°C), even when a conductive adhesive is placed between the layers to eliminate air gaps (0.186 W/m-°C).

The other set of verification experiments was to measure thermal conductivity of several polymeric samples and compare the results with published values [2]. Our measurements were conducted at 30°C, which is an average ambient temperature for parts in the vehicle. The literature data that included all the polymer types we measured was obtainable only at 20°C. As discussed later in this report, increased temperature tends to result in slightly lower thermal conductivity values for polymers. Taking this into account, and allowing for laboratory and operator-related differences, our values are reasonably close to literature values for all but two polymers (Table II). For polypropylene, the measured thermal conductivity value was 0.23 W/m-°C, and the value reported in the Encyclopedia of Polymer Science [2], was 0.12. However, other authors [8,9] determined the conductivity value of polypropylene to be in the range of 0.21 to 0.22 W/m-°C, in agreement with the value we measured. For ABS, the differences between the literature values and measured values have not yet been reconciled.

Thermal Conductivity of Polyolefin Parts:

Thermal conductivity of parts made of polyethylene, polypropylene, blends of the two polymers, and ethylene-propylene rubber were measured. The results are shown in Table III. Polyethylene samples, in general, have higher thermal conductivity values than polypropylene samples. The difference is attributable to the higher crystallinity of polyethylene, as evidenced by the heat of fusion of the polymers: 149 J/g for polyethylene and 63 J/g for polypropylene [Ref. 1, Table 6]. Thompson [2] states that polymers with higher crystallinity exhibit higher thermal conductivity values.

The effect of filler content on thermal conductivity is shown in Figure 4 for polypropylene and EPDM compositions. Higher filler content leads to higher conductivity for both polymers. At equivalent filler content, the amorphous EPDM compositions exhibit lower conductivity than those of the semicrystalline polypropylene.

Thermal Conductivity of Polvamide Parts:

The thermal conductivity of three polyamide parts are shown in Table IV. Highly filled polyamide 66 shows high conductivity values, whereas, the lower crystallinity, lightly-filled polyamide 12 has a thermal conductivity of only 0.12 W/m-°C.

Thermal Conductivitv of Parts Made of Noncrystalline Polymers:

Table V contains the thermal conductivity values measured for compositions made of polycarbonate, acrylonitrile-butadiene-styrene (ABS) terpolymer, polyacetal, SMC polyester, and polyvinyl chloride coated glass. All these polymers are amorphous and their conductivity values are relatively low, except when the composition contains a high concentration of filler.

Thermal Conductivitv of Elastomeric Parts:

Most elastomeric parts are amorphous, and most are also highly filled. The filler, in most cases, is reinforcing carbon black. Again, as in the case of amorphous thermoplastics discussed above, elastomers, in general, have low thermal conductivity, except when they are highly filled. The very low values shown in Table VI for some of the thermoplastic rubber (TPR) parts indicate that they are slightly foamed. Density measurements (Ref 1, Table III) confirm that the parts are indeed partially foamed.

Thermal Conductivitv of Foam & Other Insulation Materials:

These materials are designed to have low thermal conductivity. As seen in Table VII, the measured thermal conductivity values are very low. With our technique, we are able to measure values of 0.01 W/m-°C and higher.

It is difficult to find correlations in the data. Many variables are present that are difficult to quantify such as foam structure, cell size, and uniformity and distribution of cells inside the foam. This is, of course, in addition to density of the foam, the type of material, and the type and amount of filler used for each composition. It is generally true that lower density foams have lower thermal conductivity values (see Table VII). For parts consisting of multilayers of different materials, the thermal conductivity was measured using the whole structure, whereas density was measured for each layer as listed in the table.

Effect of Temperature on Thermal Conductivity

Five parts representing five different polymer compositions were chosen for thermal conductivity measurements at 100°C. The results are shown in Table VIII. In all cases, slightly lower thermal conductivity values were measured at 100°C, as compared to values at 30°C, for the same materials. This is in agreement with measurements reported by other authors [2,9], indicating that thermal conductivity decreases with temperature for both crystalline polymers and amorphous polymers, in the temperature region between the glass transition temperature and the melt temperature for crystalline polymers or the flow temperature for amorphous polymers. The rate of decrease depends on the polymer type.

In summary, a new and fast method for measuring the thermal conductivity of polymers has been developed. Fast and accurate measurements can be made using this method. Thermal conductivity values as low 0.01 **W/m-°C** can be accurately measured. As expected, crystalline polymers are more thermally conductive than amorphous polymers. Also, thermal conductivity increases with an increase in the concentration of filler in the composite. The data will be used for calculations of flammability parameters.

Acknowledgment

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Table I : Thermal Conductivity of Polypropylene Samples
Measurements Conducted on Several Specimens to Evaluate Effects of Sample Preparation

Part No.	Application/Function	Sample Preparation	Specimen Thickness (mm)	Thermal Conductivity (W / m-°C)
5235267	Battery/Cover	One Piece	3.28 3.28 3.28	0.217 0.226 0.236
		One Thin Piece	1.69 1.69 1.69	0.172 0.183 0.174
		Three Piece Stack	3.28 3.28 3.28	0.208 0.179 0.170
		Three Piece Stack with Conductive Adhesive	3.28 3.28	0.183 0.189

Table II : Measured Thermal Conductivity of Selected Polymers Versus Literature Values [6]

Polymer	Thermal Conductivity (W / m-°C) Measured (30°C)	Literature (20°C)
Teflon	0.32	0.25
Polystyrene	0.19	0.14
cork	0.035	0.039
Polyethylene	0.30	0.33
Polypropylene	0.23	0.12 0.22 [7] 0.21 [8]
Acrylonitrile-Butadiene Styrene (ABS)	0.21	0.33
Nylon 12	0.18	0.22
Polyoxymethylene	0.27	0.23
Polycarbonate	0.27	0.20

Table III : Thermal Conductivity of Caravan Parts Made of Polyolefins: Polyethylene (PE), Polypropylene (PP), and Ethylene Propylene Elastomer (EPDM)

Part No.	Application/Function	Polymer Type	Inorganic Filler Type	Filler Concentration (%) Inorganic Ash	Filler Concentration (%) Organic Residue	Thermal Conductivity (W / m-°C)
4707580A	Wire Harness/Tube	PE		0.3	0	0.37
4678345A	Airduct/small	PE		0	0	0.31
4883140A	Fuel Tank/Structure	PE		0	0	0.30
4364944A	Battery/Casing Top	PE/PP		0.3	0	0.17
43649448	Battery/Side & Bottom	PE/PP		0.3	0	0.21
4612512A	Resonator/Structure	PP		20.4	1	0.23
4683264A	Brake/Fluid Reservoir	PP		0	0	0.19
46832648	Brake/Reservoir Cap	PP		0.8	0	0.21
4716895	Wheel/Well Cover	PP				
4734063	HVAC/Unit Cover	PP	Mg,Si(Talc)	36.1	2	0.39
4734073	HVAC/Fan Top Cover	PP				0.39
4734074	HVAC/Fan Bot. Cover	PP	Talc	36.1	0	0.39
4734081	HVAC/Deflector	PP				0.59
4734225	HVAC/Actuator	PP		30.4	0	0.34
4734367	HVAC/Unit Housing	PP		35.2	0	0.33
5235267A	Battery/Cover	PP		0.2	I	0.23
46125128	Resonator/Inner Tube	EPDM	Si,Ca	I.9	43	0.30
4612512C	Resonator Efflue. Tub/ Efflue.Tu e	EPDM		I.7	45	0.36
4683264C	Brake Cyl./Cap Liner	EPDM				0.36
3009	Wire Harness/Groumet	EPDM		I.9	49	0.45

Table IV : Thermal Conductivity of Polyamide Parts

Part No.	Application/Function	Polymer Type	Filler Type	Filler Concentration (%) Inorganic Ash	Filler Concentration (%) Organic Residue	Thermal Conductivity (W / m-°C)
4734041 A	HVAC/Unit Door	Polyamide 66		39.3	0	0.58
4734042A	HVAC/Unit Door	Polyamide 66		39.2	5	0.40
48831408	Fuel System/Hose	Polyamide 12		0.4	0	0.18

Table V : Thermal Conductivity of Polycarbonate (PC), Polyether, Acrylonitrile-Butadiene-Styrene (ABS), and Polyester Parts

Part No.	Application Function	Polymer Type	Filler Type	Filler Concentration (%) Inorganic Ash	Filler Concentration (%) Organic Residue	Thermal Conductivity (W / m-°C)
4857041 A	Headlight/Lens	PC		0.2	18	0.20
4857041 B	Headlight/Backing	PC		0.2	21	0.22
4857041 E	Headlight/Leveling Mechanism	PC		0	19	0.19
JF48SK5C	I P/Structure	PC		0.4	10	0.18
PL98SX8A	IP/Trim	PC		0.2	16	0.27
4857041 C	Headlight/Retainer	Polyacetal (POM, Delrin)		0.2	0	0.27
4707743C	Door Lock/Contact Structure	ABS		4.4	0	0.21
4716051	Windshield/Wiper Tray Structure	SMC Polyester	Mg,Al,Si,Ca (glass fiber, CaC03)	4.72	4	0.37
47168968	Bulk Head/Insulation	PVC Coating Over Glass	Mg,Al,Si,Ca,Ti,Ba (glass,CaCO3,Kaolin)	44.9	4	0.23

Table VI : Thermal Conductivity of Elastomeric Parts

Part No.	Application Function	Polymer Type	Filler Type	Filler Concentration (%) Inorganic Ash	Organic Residue	Thermal Conductivity (W / m-°C)
46125128	Resonator/Intake Tube	EPDM	Si,Ca	1.9	43	0.30
4612512C	Resonator/Effluent Tube	EPDM		1.7	45	0.36
4674711 B	Kick Panel/Insulation	PVC	Si,S,Ca,Ba ($CaCO_3$,$BaSO_4$)	52.9	0	0.25
46753598	Hood/Weatherstripping	EPDM	CaC03	14.6	32	0.21
4680152	Steering Column/Outer Boot	Polyether/Co-Polyester(Hytrel)	Si,Ca,S	18.1	1	0.24
4680250A	Steering Column/Inner Boot	Natural Rubber	Si,S,Ca	7.7	33	0.24
4683264C	Brake Reservoir/Cap Liner	EPDM				0.20
4716896C	Bulk Head/Engine Side	PVC, Elastomer		42.0	1	0.10
4734039B	HVAC/Rubber Seal	TPR(PP/EPDM)		11.1	1	0.09
4734041 B	HVAC/Rubber Seal	TPR		13.6	1	0.13
4734042B	HVAC/Rubber Seal	TPR		12.5	2	0.05
4734724	HVAC/Tube	TPR	Al,Si,Sn	11.2	4	0.33
JF48SK5B	Instrument Panel/Cover	PVC	Si,Ca	8.0	9	0.14
3009	Wire Harness/Grommet	EPDM		1.9	49	0.45

Table VII : Thermal Conductivity of Polymeric Foams and Insulation Materials

Part No.	Application/Function	Polymer Type	Filler Type	Filler Concentration (%) Inorganic Ash	Organic Residue	Thermal Conductivity (W / m-°C)	Density (g / cc)
467471 I A	Silencer/Insulation		Si,S,Ba	11.0	0	0.022	0.02
4675359A	Cowl/Weatherstrip	EPDM	Mg,Si,S,Ca,Zn	15.9	21.1	0.074	0.44
46753598	Cowl/Weatherstrip	EPDM	CaC03	14.6	32	0.21	0.41
4677780	HVAC Resistor					0.046	
46783456	Air Duct/Assembly	PE/PP				0.122	0.95, I.04
4680250C	Steering Column/Ins.	Cotton/Polyester Other Fiber		2.9	15.8	<0.01	I.26,0.22
4716345A	Fender/Insulation Low Density Foam	Polystyrene (PS)	Na,Mg,Al,Si, Ca,Zn (Kaolin)	32.8	2.4	0.17	0.90
47163458	Fender/Insulation High Density Foam	PS	Al,Si,Ti,Zn (Kaolin)	39.0	3.2	0.102	0.13
4716832A	Hoodliner/Insulation	PET, Cellulose Fibers, Epoxy	Mg,Si,S,Ca, Cu ,Zn (Talc)	2.4	29.5	0.036	0.09
47168328	Hoodliner/Face	PET	Mg,Si,Ca,Sb	1.3	31.1	0.087	0.66
4734025	HVAC/Unit Door			0.2	6.6	co.01	0.11
47340398	HVAC/Rubber Seal	TPR (PP/EPDM)		11.1	I	0.09	0.93
4734041 B	HVAC/Rubber Seal	TPR		13.6	I	0.13	0.97
47340428	HVAC/Rubber Seal	TPR		12.5	2	0.05	0.98
4734066	HVAC/Seal					0.012	0.11
4734067A	HVAC/Unit Seal	Acrylonitrile/Poly-vinyl Chloride Blend	CaC03	16.9	13.5	0.016	0.10
4734370	HVAC/Unit Seal	Acrylonitrile/Poly-vinyl Chloride Blend	Mg,Si,S,Ca CaC03, Talc	18.5	13.9	0.153	0.07
4734396	HVAC/Unit Seal					0.029	0.12
4734650	HVAC/Unit Seal					0.034	0.11
4734651	HVAC/Unit Seal					0.041	0.17
JF48SK5A	I/P /Foam Insulation	Polyether Urethane (PPO/MDI)		0.6	12.9	0.035	0.11
PL98SX8B	I/P Shelf Insulation	Polyether Urethane	Sr,Ba,S	37.3	0	0.062	0.09
GJ42SK4	Headliner	PET Fabric, Polyurethane, Nylon, Other	Si,Ca			0.037	0.69,0.IO 0.06,0.I2

Table VIII : Effects of Temperature on Thermal Conductivity of Polymers

Part Number	Application/Function	Polymer Type	Thermal Conductivity (W / m°C) 30°C	100°C
4716345B	Fender/High Density Foam Insulation	Polystyrene	0.10	0.04
4716895	Wheel Well/Cover	Polypropylene	0.24	0.16
4734041A	HVAC/Unit Door	Polyamide 66	0.58	0.57
4857041 A	Headlight/Lens	Polycarbonate	0.20	0.18
4857041 C	Headlight Retainer	Polyacetal	0.27	0.25

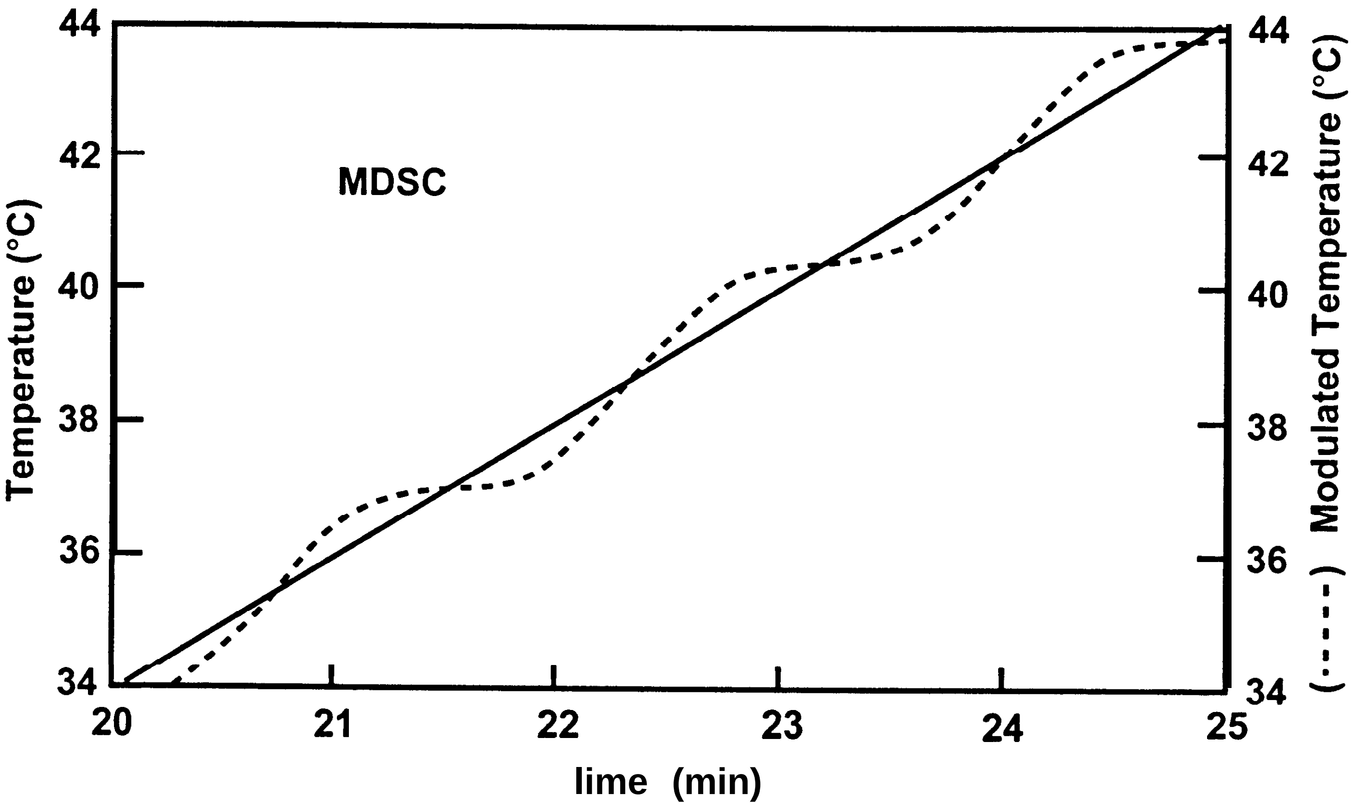

Figure 1. Sine wave heat input imposed over an underlying constant rate in a modulated differential scanning calorimeter (MDSC).

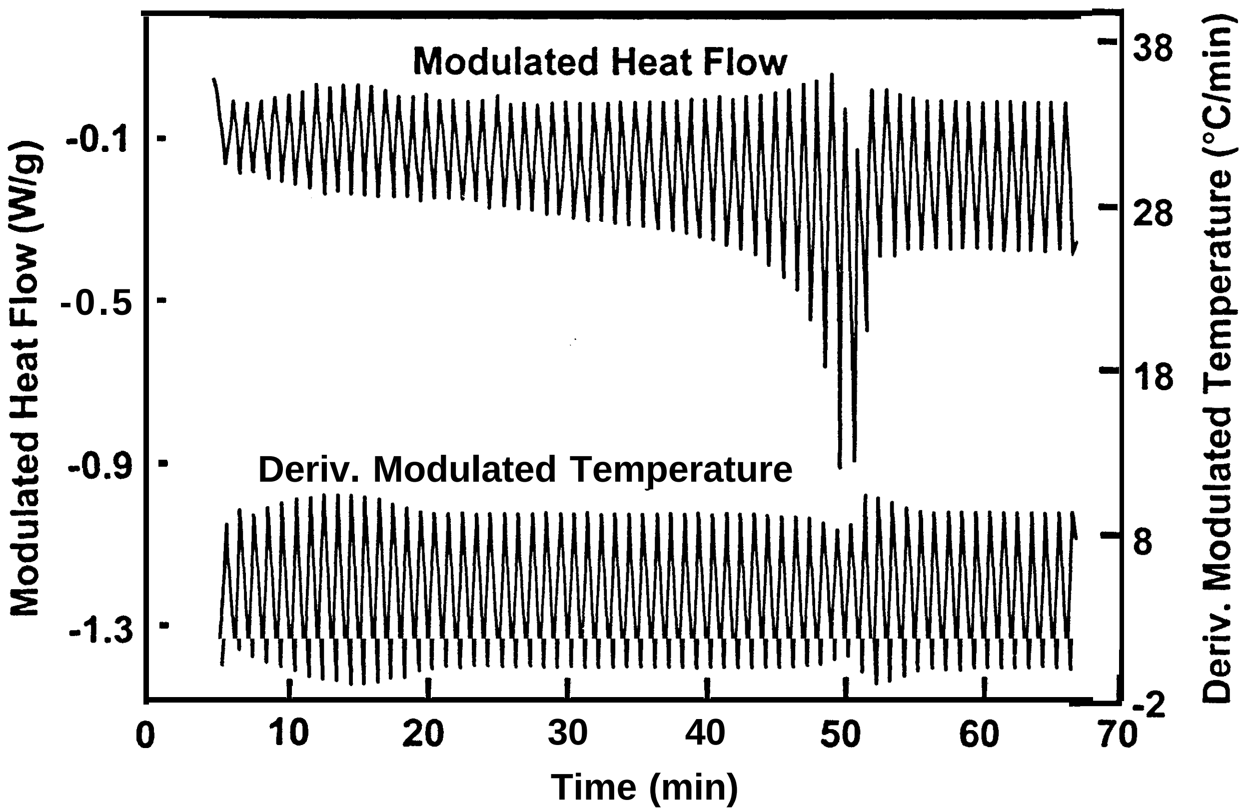

Figure 2. MDSC raw data for a polypropylene sample taken from a Camaro case heater cover.

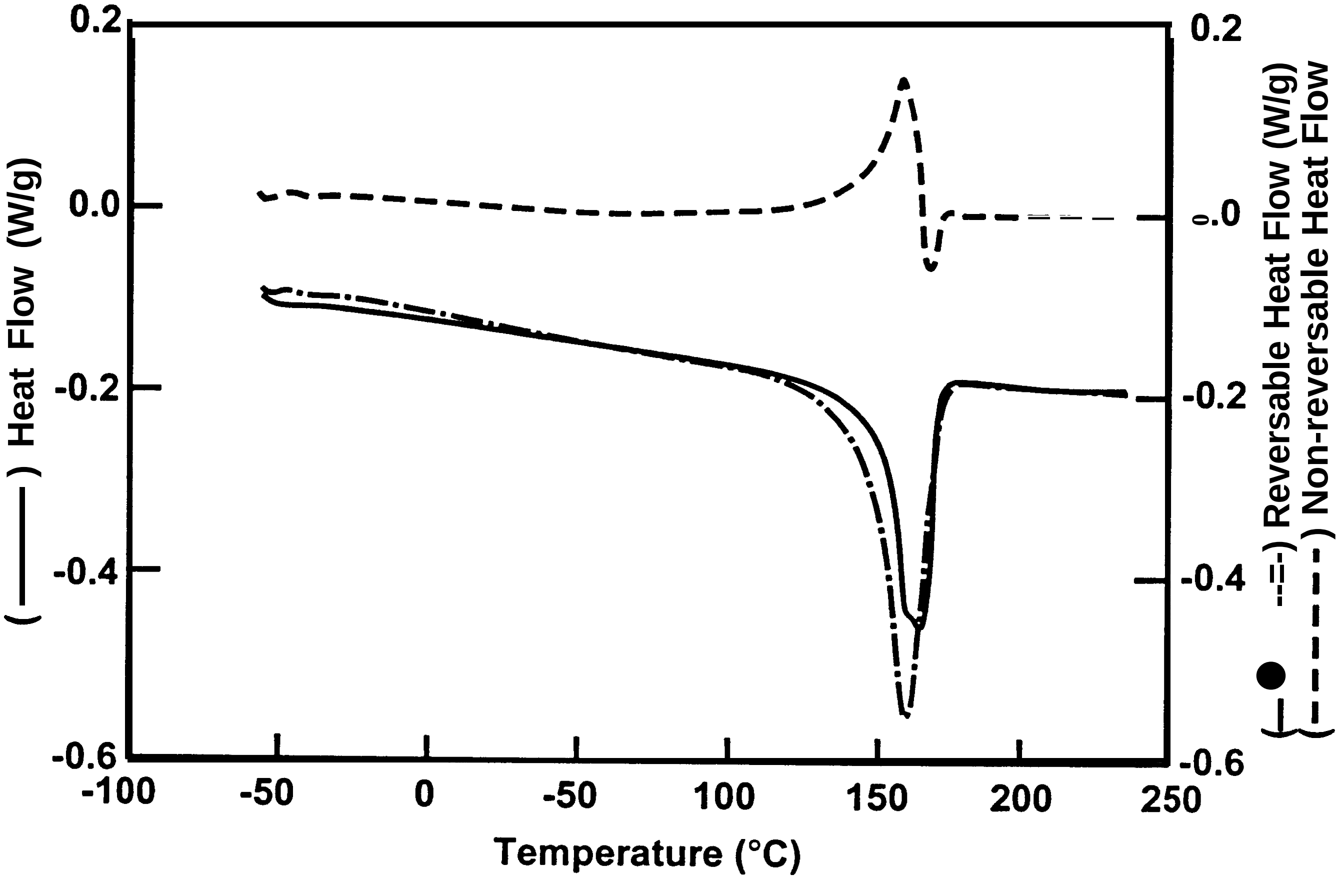

Figure 3. MDSC charts for a polypropylene sample taken from a Camaro case heater cover showing over all heat flow, reversable heat flow and non-reversable heat flow.

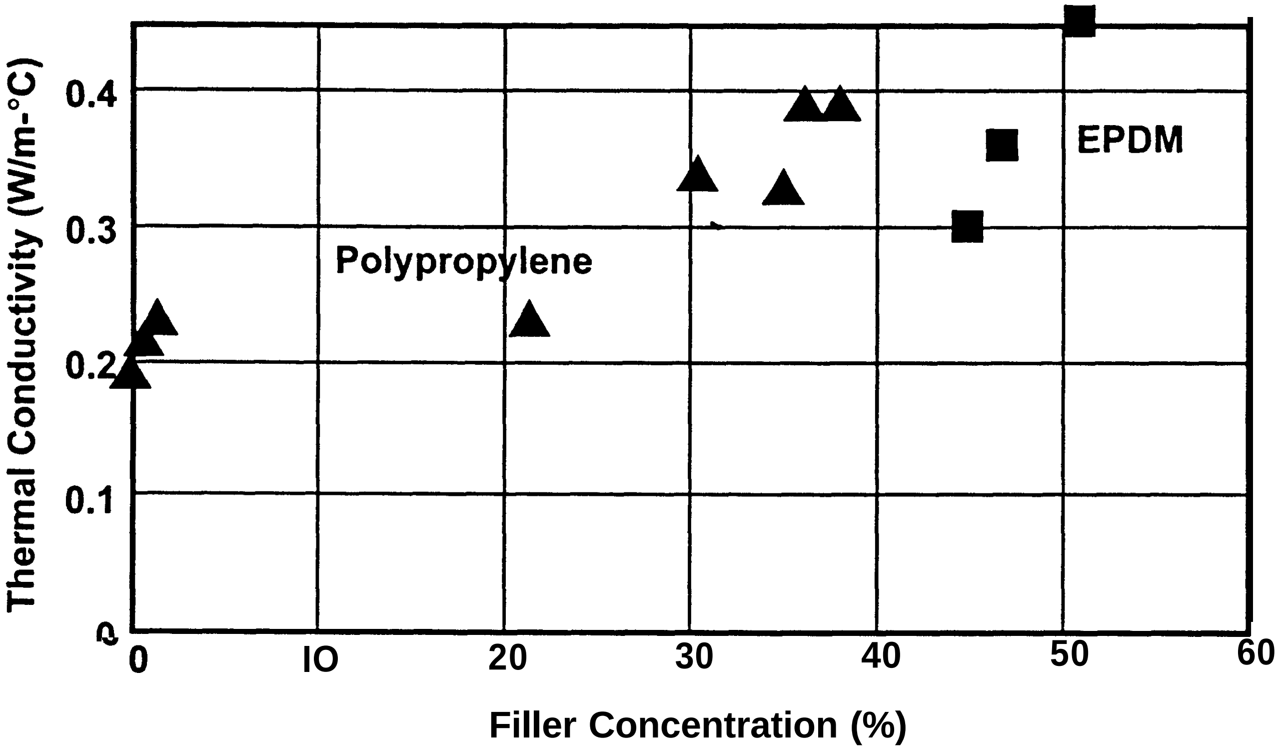

Figure 4. Effect of filler concentration on thermal conductivity of polypropylene and EPDM.