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# Thermophysical Properties of BKC 44306 and BKC 44307 PMDI Urethane Solid and Foams

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**Abstract**

Accurate knowledge of thermophysical properties of urethane foam is considered extremely important for meaningful models and analyses to be developed of scenarios wherein the foam is heated. Its performance at temperature requires a solid understanding of the foam material properties at temperature. Also, foam properties vary with density/porosity. An experimental program to determine the thermal properties of the two foams and their parent solid urethane was developed in order to support development of a predictive model relating density and thermal properties from first principles.

Thermal properties (thermal conductivity, diffusivity, and specific heat) of the foam were found to vary with temperatures from 26˚C to 90˚C. Thermal conductivity generally increases with increasing temperature for a given initial density and ranges from .0433 W/mK at 26˚C to .0811 W/mK at 90˚C; thermal diffusivity generally decreases with increasing temperature for a given initial density and ranges from .4101 $mm^2/s$ at 26˚C to .1263 $mm^2/s$ at 90˚C; and specific heat generally increases with increasing temperature for a given initial density and ranges from .1078 $MJ/m^3K$ at 26˚C to .6323 $MJ/m^3K$ at 90°C.

Thermal properties of the solid urethane were also found to vary with temperatures from 26˚C to 90˚C. Average thermal conductivity generally increases with increasing temperature for a given initial density and ranges from 0.126 to 0.131 W/mK at 26˚C to 0.153 to 0.157 W/mK at 90˚C; average thermal diffusivity generally decreases with increasing temperature for a given initial density and ranges from 0.142 to 0.147 $mm^2/s$ at 26˚C to 0.124 to 0.125 $mm^2/s$ at 90˚C; and average specific heat generally increases with increasing temperature for a given initial density and ranges from 0.889 to 0.899 $MJ/m^3K$ to 1.229 to 1.274 $MJ/m^3K$ at 90°C.

The density of both foam and solid urethane decreased with increasing temperature.

# ACKNOWLEDGMENTS

This work was completed in the Geomechanics Laboratory at Sandia National Laboratories. The authors would like to thank Edward Russick for making the samples and would like to acknowlwedge the careful review of this report by Scott Broome.

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## FIGURES



## TABLES

# 1. INTRODUCTION

Accurate knowledge of thermophysical properties of PMDI (urethane) foam is considered extremely important for meaningful models and analyses to be developed of scenarios wherein the foam is heated. Its performance at temperature requires a solid understanding the foam material properties at temperature. Also, foam properties vary with density/porosity. An experimental program to determine the thermal properties of the two foams and their parent "solid" urethanes was developed in order to support development of a predictive model relating density and thermal properties from first principles.

Thermal conductivity, the property of a material to conduct heat, thermal diffusivity, the measure of thermal inertia, and the specific heat, the amount of heat per unit mass required to raise the temperature by one $^{o}C$, were each determined in this study. The operative mechanisms resulting in the observed changes of these thermal properties is beyond the scope of this study; minor aberrations in "smooth curves" obtained for most samples could be the result of experimental error and sample changes (perhaps chemical in nature) induced by heating the samples.

# 2. SAMPLE HANDLING AND MEASUREMENTS

Thermal property measurements (thermal conductivity, diffusivity, and specific heat) were completed on a series of foam and urethane samples supplied by the sponsor and consisted of foams in the series PMDI BKC44306 and BKC44307. The foam samples were made to vary in density by changing the water content (the blowing agent) and the amount of over-packing in a cylindrical mold that produced an initial sample approximately 5 cm in diameter and 11 cm in height. In addition, foam samples were made of each of the two materials that had been dried to remove the blowing agent. These samples, which called "solid urethane" did contain some bubbles resulting from reaction with either absorbed or residual moisture or entrained air from the mixing process. Therefore, these urethane samples are less dense than a true solid urethane.

Thermal measurements were made at ambient pressure and moisture conditions using a transient method based on the theory of the transient plane source technique. All property determinations were made with each measurement using the same apparatus, a Hot Disk Thermal Constants Analyzer (TCA). The apparatus employs a transient plane source device which is used to measure material thermal transport properties—thermal conductivity, thermal diffusivity and specific heat. The transient plane source method uses a plane sensor to function simultaneously as a heat source and resistance thermometer able to detect temperature changes as slight as 0.1 mK. The sensor is sandwiched between two samples of the material to be tested. Passing a current through the sensor increases its temperature by as much as a few degrees and causes a pulse of heat to enter the sample material. The ability of the sample material to conduct heat away from the sensor affects the temperature increase of the sensor. By monitoring the change in sensor temperature over time, therefore, the TCA system can deduce the thermal conductivity of the sample.

Using a nickel sensor embedded in a Kapton or mica coating, the TCA device used in this work (the ThermTest TPS1500 model) can make measurements from cryogenic temperatures to 1000K. The range of measurable thermal conductivities is 0.01–20 W/mK; the maximum measurable specific heat capacity is 5 MJ/$m^3$K. Samples can be as small as 3 mm in height by 13 mm in diameter, with no maximum limit. In addition to solids, measurements can be made in porous materials, powders and pastes.

The Hot Disk® sensors used for these measurements serve as a heat source to increase sample temperature and as resistance thermometers for recording temperature increase over time. The apparatus includes a programmable oven to house the sample and sensor portion of the test system, and a computer for data acquisition, data analysis, and program control (Figure 1).

Samples are heated from one temperature to the next at 1-2 degrees C per minute; at each temperature the sample equilibrated for a few hours before a measurement was made.  Measurements were made at room temperature and at specified temperature intervals up to 90$^o$C.

The foam samples were supplied as paired discs of similar density. The solid urethane samples were supplied as cylinders, with a small amount of bubbles present, less at bottom, and a greater amount at the top. Solid urethane samples were carefully cut from cylinders of material supplied using a wire saw followed by abrasive paper, 2.0” diameter and 1” in length. The thermal measurement was made across a matched interface in each sample. A flat uniform surface to seat the sensor is important to obtaining reproducible measurements.

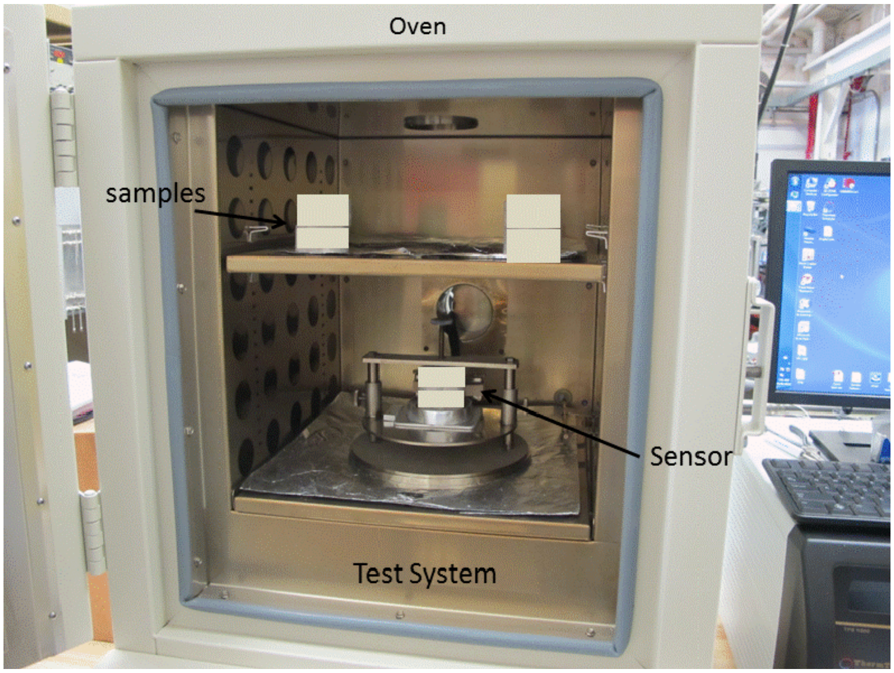


**Figure 1 Thermal Measurements Test System.**

## 2.1 Porous Urethane Foam Sample and Thermophysical Property Measurements

The foam samples have lower density once the contact rind was removed from the flat surface; this post-grinding value is that used in subsequent presentations in this report (Table 1). Density of the foam samples ranges from 5.51 pcf to 25.94 pcf.

Thermal conductivity, thermal diffusivity and specific heat measurements are presented in Table 2. Each line of data represents that from a matched pair sample.

For a given sample (density) over the temperature range up to 90$^{o}$C, thermal conductivity tends to increase, thermal diffusivity tends to decrease, and and specific heat tends to increase with increasing temperature, Figures 2, 3, and 4, respectively.

For a given measurement  temperature, thermal conductivity tends to increase, thermal diffusivity tends to decrease, and and specific heat tends to increase with increasing density, Figures 5, 6, and 7, respectively.

| | Initial | | | | | | Post-grinding | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ID | Weight (g) | Diameter (in) | Height (in) | Volume ($in^3$) | Calc. density (pcf) | Noted density (pcf) | Weight (g) | Height (in) | Volume ($in^3$) | Calc. density (pcf) |
| 44306-10 | 21.28 | 1.98 | 1.00 | 3.08 | 26.27 | 26.16 | 19.54 | 0.93 | 2.86 | 25.94 |
| 44306-10 | 21.13 | 1.99 | 1.02 | 3.17 | 25.32 | 25.21 | 19.15 | 0.94 | 2.92 | 24.90 |
| 44306-10 | 15.55 | 1.98 | 1.00 | 3.08 | 19.20 | 19.19 | 14.15 | 0.93 | 2.86 | 18.79 |
| 44306-10 | 15.69 | 1.99 | 1.02 | 3.17 | 18.80 | 18.83 | 14.04 | 0.93 | 2.89 | 18.45 |
| 44307-4 | 12.74 | 1.99 | 1.02 | 3.17 | 15.27 | 15.10 | 11.36 | 0.94 | 2.92 | 14.77 |
| 44307-4 | 10.63 | 1.99 | 1.00 | 3.11 | 12.99 | 12.90 | 9.26 | 0.89 | 2.77 | 12.72 |
| 44306-10 | 10.57 | 1.98 | 1.00 | 3.08 | 13.05 | 13.04 | 9.26 | 0.90 | 2.77 | 12.70 |
| 44306-10 | 10.32 | 1.99 | 1.02 | 3.17 | 12.37 | 12.41 | 9.10 | 0.93 | 2.89 | 11.96 |
| 44307-4 | 8.87 | 1.99 | 1.02 | 3.17 | 10.63 | 10.58 | 7.79 | 0.91 | 2.83 | 10.46 |
| 44307-4 | 7.40 | 1.99 | 1.00 | 3.11 | 9.04 | 9.08 | 5.94 | 0.83 | 2.58 | 8.75 |
| 44307-4 | 4.92 | 1.99 | 1.00 | 3.11 | 6.01 | 6.04 | 4.06 | 0.87 | 2.71 | 5.70 |
| 44307-4 | 4.91 | 1.99 | 1.02 | 3.17 | 5.88 | 5.85 | 3.88 | 0.86 | 2.67 | 5.51 |

**Table 1 Sample dimensions and density determinations, porous foam.**

| | | Thermal conductivity (W/mK) | | | Thermal diffusivity ($mm^2/s$) | | | Specific heat ($MJ/m^3K$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ID | Calc. density (pcf) | 26°C | 60°C | 90°C | 26°C | 60°C | 90°C | 26°C | 60°C | 90°C |
| 44306-10 | 25.94 | 0.0743 | 0.0788 | 0.0799 | 0.1473 | 0.1396 | 0.1263 | 0.5046 | 0.5646 | 0.6323 |
| 44306-10 | 24.90 | 0.0741 | 0.0788 | 0.0811 | 0.1439 | 0.1385 | 0.1312 | 0.5147 | 0.5692 | 0.6180 |
| 44306-10 | 18.79 | 0.0656 | 0.0721 | 0.0735 | 0.1544 | 0.1661 | 0.1426 | 0.4250 | 0.4342 | 0.5153 |
| 44306-10 | 18.45 | 0.0658 | 0.0703 | 0.0734 | 0.1487 | 0.1503 | 0.1433 | 0.4422 | 0.4677 | 0.5121 |
| 44307-4 | 14.77 | 0.0518 | 0.0569 | 0.0606 | 0.1830 | 0.1816 | 0.1804 | 0.2830 | 0.3133 | 0.3361 |
| 44307-4 | 12.72 | 0.0534 | 0.0569 | 0.0603 | 0.1968 | 0.1796 | 0.1773 | 0.2713 | 0.3170 | 0.3398 |
| 44306-10 | 12.70 | 0.0541 | 0.0568 | 0.0615 | 0.1829 | 0.1793 | 0.1683 | 0.2958 | 0.3165 | 0.3654 |
| 44306-10 | 11.96 | 0.0541 | 0.0576 | 0.0614 | 0.1815 | 0.1723 | 0.1663 | 0.2983 | 0.3343 | 0.3694 |
| 44307-4 | 10.46 | 0.0479 | 0.0515 | 0.0552 | 0.2598 | 0.2443 | 0.2458 | 0.1844 | 0.2109 | 0.2244 |
| 44307-4 | 8.75 | 0.0481 | 0.0524 | 0.0549 | 0.2623 | 0.2548 | 0.2430 | 0.1833 | 0.2056 | 0.2258 |
| 44307-4 | 5.70 | 0.0442 | 0.0472 | 0.0507 | 0.4101 | 0.3742 | 0.3834 | 0.1078 | 0.1262 | 0.1323 |
| 44307-4 | 5.51 | 0.0433 | 0.0476 | 0.0506 | 0.3954 | 0.3791 | 0.3819 | 0.1095 | 0.1255 | 0.1325 |

**Table 2 Thermal conductivity, thermal diffusivity, specific heat determinations, porous foam.**

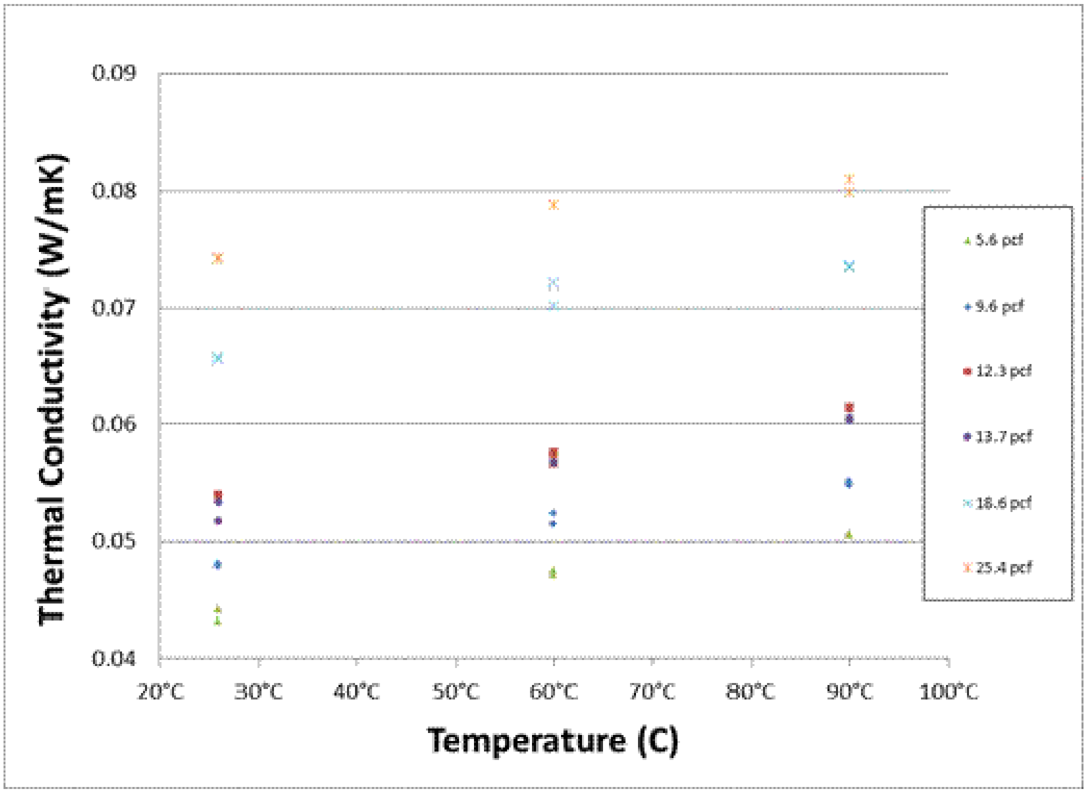


**Figure 2** **Thermal Conductivity vs temperature, porous urethane foam.**

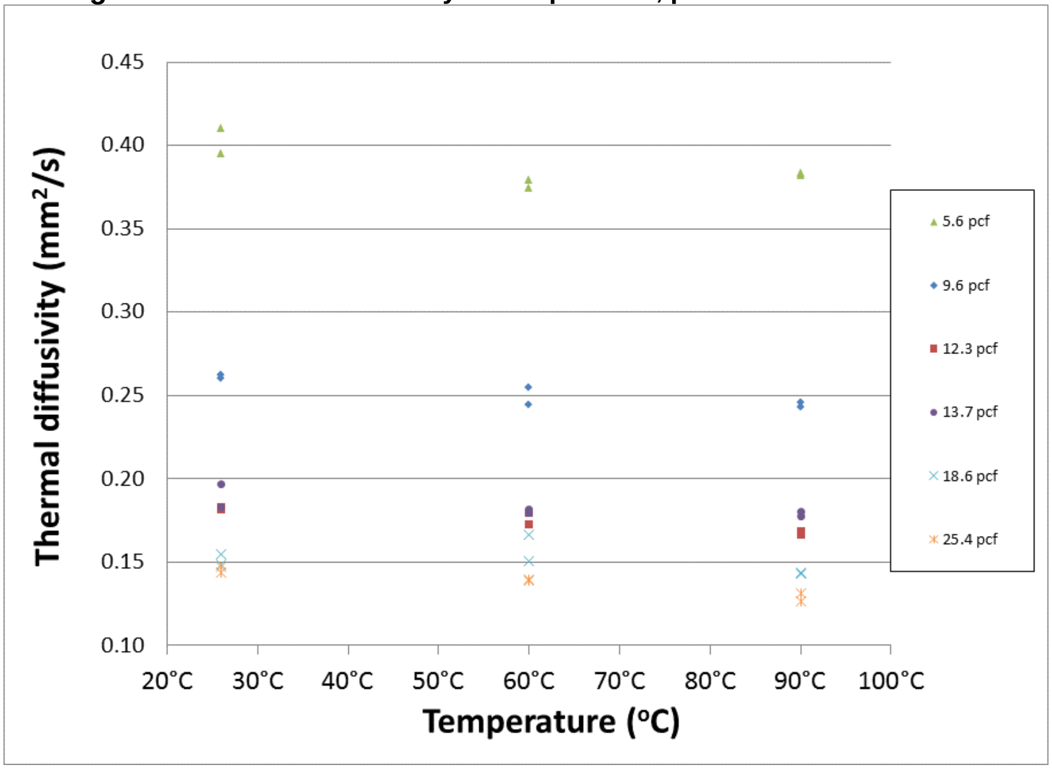


**Figure 3** **Thermal diffusivity vs temperature, porous urethane foam.**

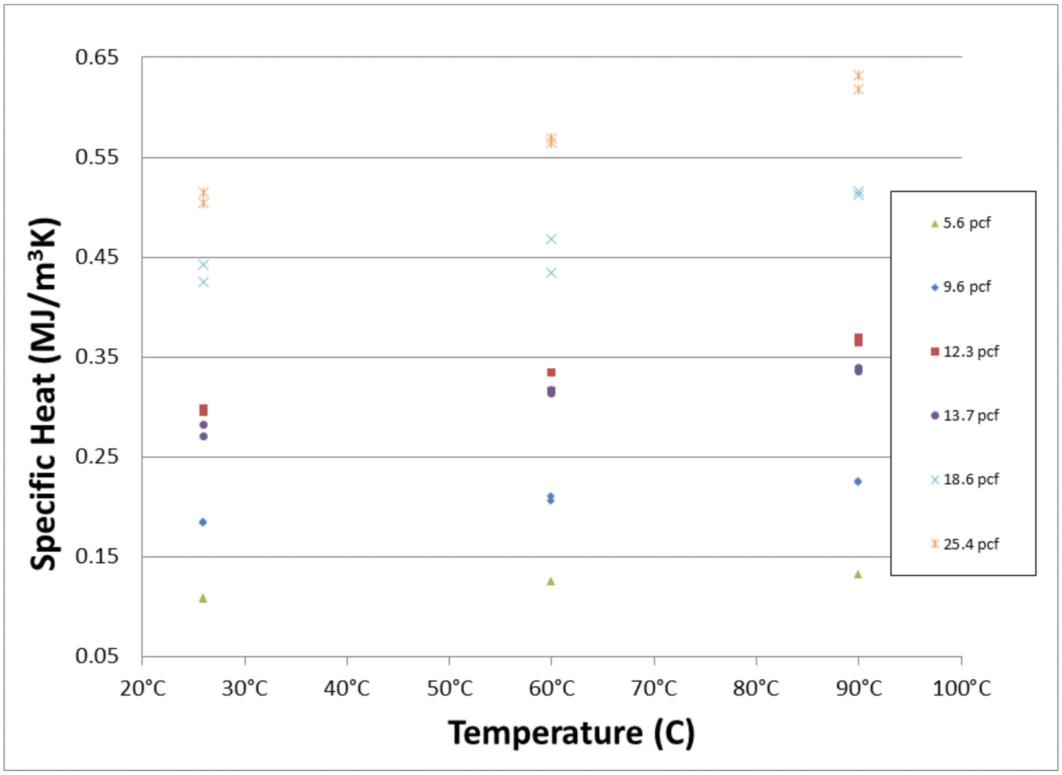


**Figure 4** Specific heat vs temperature, porous urethane foam.

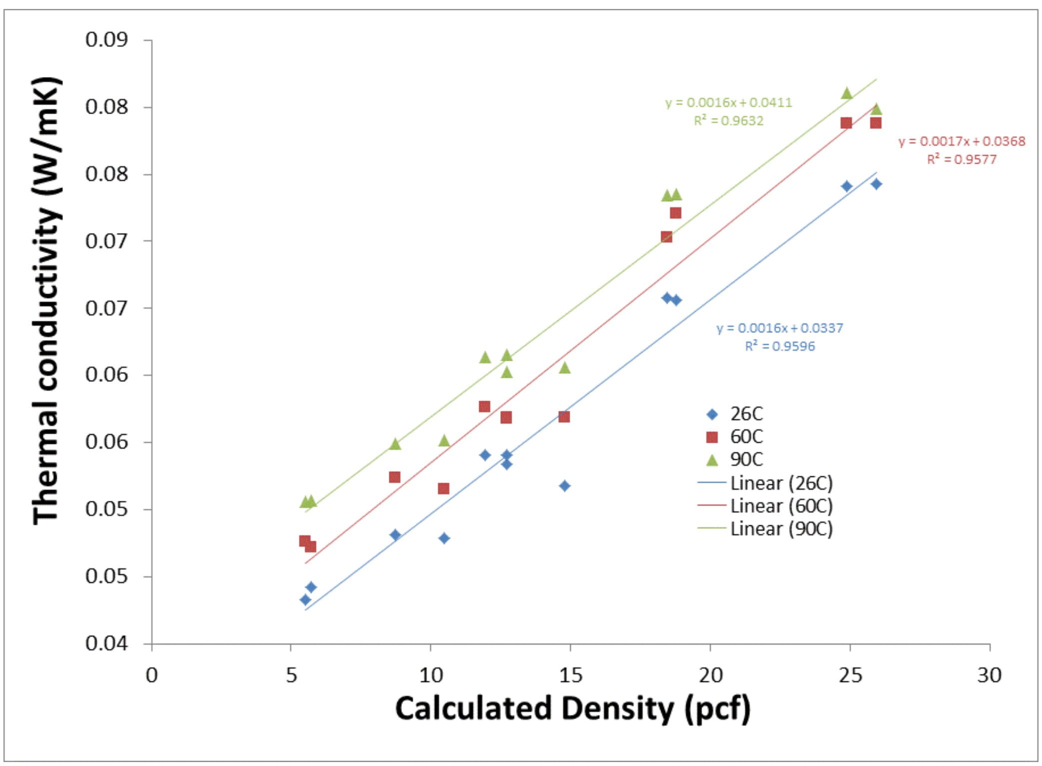


**Figure 5** Thermal conductivity versus density, porous urethane foam.

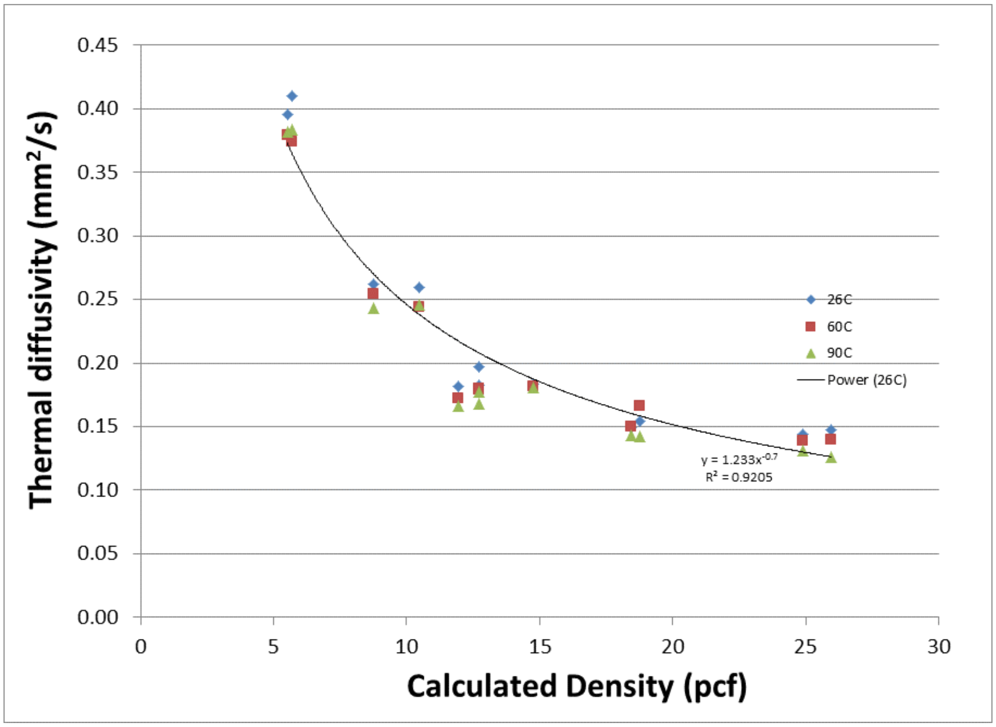


**Figure 6** **Thermal diffusivity versus density, porous urethane foam.**

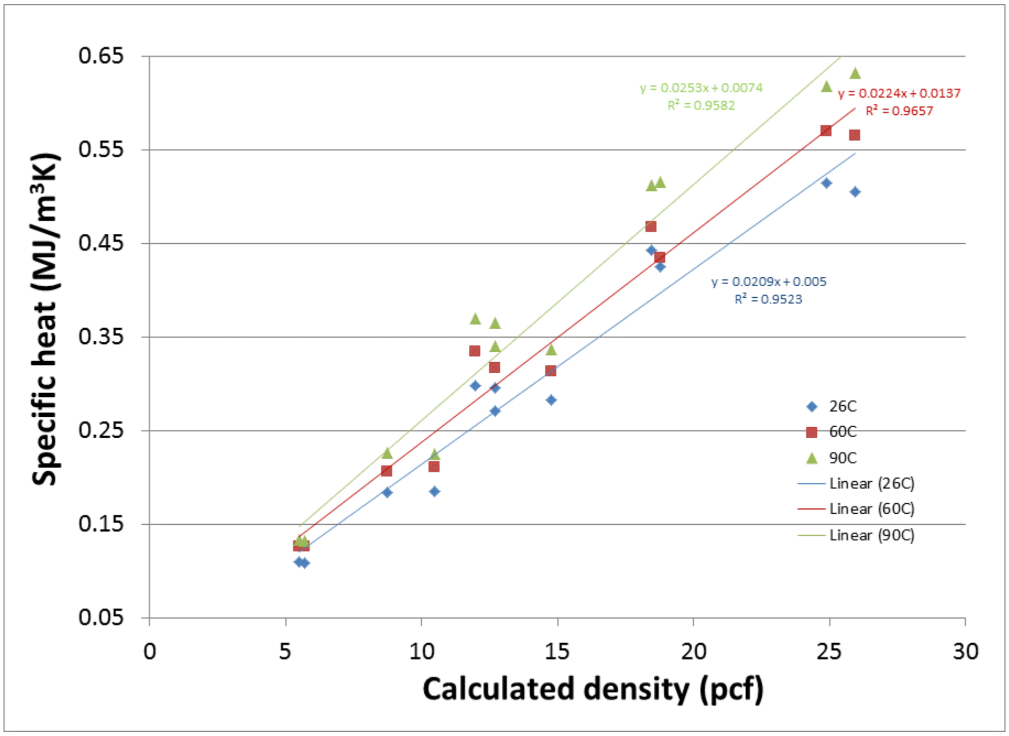


**Figure 7** **Specific Heat versus density, porous urethane foam.**

## 2.2 Solid Urethane Sample and Thermophysical Property Measurements

**Results and Comments**

Solid urethane sample discs are labeled for thermal analysis in Figure 8. For most sample/temperature combinations, four sets of thermal property measurements were taken and results are given in Tables 3, 4, and 5.

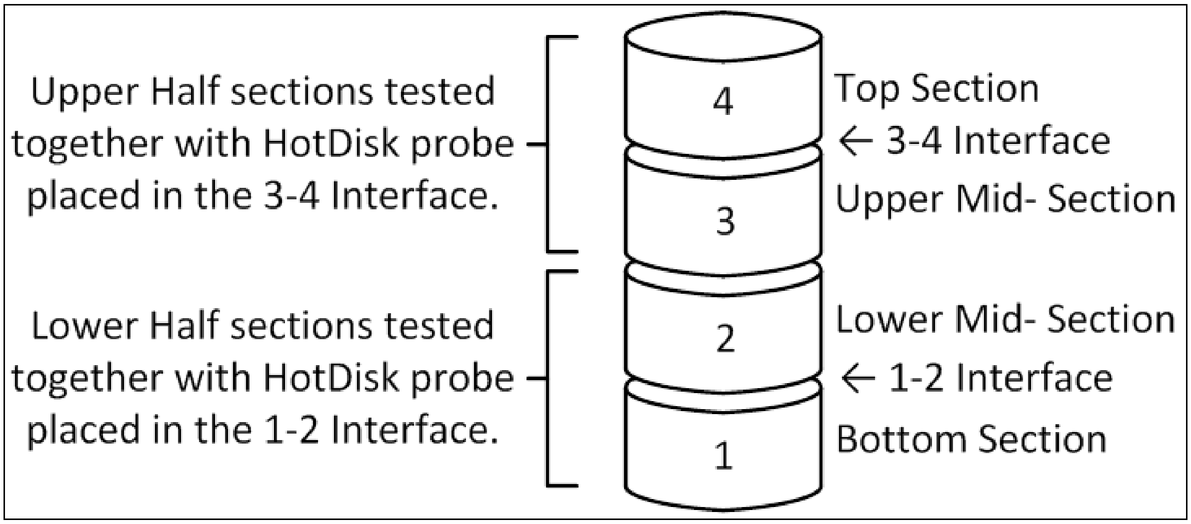


**Figure 8 Schematic of sample layout**

For a given sample set for both solid urethanes, (with similar initial density) over the temperature range up to 90$^o$C, thermal conductivity tends to increase, thermal diffusivity tends to decrease, and and specific heat tends to increase with increasing temperature, Figures 9, 10, and 11, respectively. There is perhaps a plateau in the thermal diffuivity and specific heat data between 80$^o$C and 90$^o$C.

Thermal conductivity decreases with increasing density for both 44306 and 44307 urethanes, (Figure 12), thermal diffusivity increases with increasing density (Figure 13) and specific heat decreases with increasing density (Figure 14).  Linear fits to the data are presented and appear reasonable approximations to the data set.

The measurement sets on 44306 urethane are more widely spaced than for the 44307 urethane. This may be rooted in the density variation versus temperature observed (Figure 15). The density of both urethanes tends to decrease with increasing temperature. The larger density variation in 44307 vesus 44306 from top to bottom is noted and perhaps relates to the amount of bubbles in it.

# 3 CONCLUDING COMMENTS

In this study, thermophysical properties of two samples each of two solid urethanes 44306 and 44307, and their foam product were measured with increasing temperature. Measurements on solid urethane may provide a data set for development of models to predict thermal properties for foam equivalents as a function of temperature; Measurements on foamed urethane may provide a data set for validation of models to predict thermal properties for urethane foams as a function of temperature. The change in density of these materials as a function of temperature may also need to be considered in analyses performed. Time dependence, cycling versus single path increase, reproducibility for multiple samples is not considered in this study.

## Table 3 44306 and 44307 Solid Urethane Epoxy Sample Dimensions, Density

### 44306 Lower Half Data

**Sample: 44306-1, Bottom section**

| Temp, °C | Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|---|
| 25 | 1.988 | 1.013 | 54.288 | 65.64 |
| 40 | 1.992 | 1.014 | 54.297 | 65.32 |
| 50 | 1.992 | 1.013 | 54.279 | 65.36 |
| 60 | 1.993 | 1.015 | 54.256 | 65.14 |
| 70 | 1.994 | 1.016 | 54.269 | 65.03 |
| 80 | 1.995 | 1.016 | 54.222 | 64.90 |
| 90 | 1.995 | 1.016 | 54.178 | 64.85 |

**Sample: 44306-2, Lower Mid-section**

| Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|
| 1.984 | 1.051 | 55.058 | 64.42 |
| 1.992 | 1.058 | 55.071 | 63.49 |
| 1.989 | 1.054 | 55.051 | 63.90 |
| 1.989 | 1.054 | 55.031 | 63.88 |
| 1.990 | 1.056 | 55.044 | 63.71 |
| 1.990 | 1.056 | 54.995 | 63.65 |
| 1.991 | 1.055 | 54.952 | 63.60 |

### 44306 Upper Half

**Sample: 44306-3, Upper Mid-section**

| Temp, °C | Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|---|
| 25 | 1.987 | 1.056 | 54.994 | 63.85 |
| 40 | 1.990 | 1.059 | 55.006 | 63.49 |
| 50 | 1.989 | 1.059 | 54.984 | 63.53 |
| 60 | 1.990 | 1.059 | 54.963 | 63.44 |
| 70 | 1.992 | 1.060 | 54.976 | 63.27 |
| 80 | 1.992 | 1.061 | 54.926 | 63.15 |
| 90 | 1.993 | 1.059 | 54.879 | 63.15 |

**Sample: 44306-4, Top Section**

| Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|
| 1.987 | 1.024 | 53.232 | 63.73 |
| 1.991 | 1.026 | 53.244 | 63.37 |
| 1.990 | 1.025 | 53.222 | 63.47 |
| 1.991 | 1.026 | 53.203 | 63.32 |
| 1.993 | 1.028 | 53.214 | 63.08 |
| 1.993 | 1.028 | 53.164 | 63.02 |
| 1.994 | 1.028 | 53.12 | 62.91 |

### 44307 Lower Half Data

**Sample: 44307-1, Bottom section**

| Temp, °C | Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|---|
| 25 | 1.996 | 0.962 | 53.315 | 67.33 |
| 40 | 1.999 | 0.966 | 53.325 | 66.87 |
| 50 | 1.999 | 0.967 | 53.312 | 66.78 |
| 60 | 2.000 | 0.969 | 53.299 | 66.56 |
| 70 | 2.001 | 0.967 | 53.315 | 66.65 |
| 80 | 2.004 | 0.968 | 53.275 | 66.33 |
| 90 | 2.005 | 0.968 | 53.244 | 66.23 |

**Sample: 44307-2, Lower Mid-section**

| Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|
| 1.996 | 1.013 | 53.670 | 64.37 |
| 2.000 | 1.013 | 53.682 | 64.13 |
| 1.998 | 1.014 | 53.668 | 64.17 |
| 1.999 | 1.015 | 53.653 | 64.03 |
| 2.001 | 1.017 | 53.669 | 63.79 |
| 2.004 | 1.018 | 53.629 | 63.49 |
| 2.004 | 1.017 | 53.598 | 63.52 |

**Sample: 44307-3, Upper Mid-section**

| Temp, °C | Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|---|
| 25 | 1.996 | 1.033 | 54.148 | 63.69 |
| 40 | 1.999 | 1.037 | 54.161 | 63.26 |
| 50 | 1.999 | 1.035 | 54.144 | 63.37 |
| 60 | 2.000 | 1.036 | 54.130 | 63.23 |
| 70 | 2.001 | 1.038 | 54.150 | 63.06 |
| 80 | 2.004 | 1.039 | 54.105 | 62.76 |
| 90 | 2.005 | 1.039 | 54.072 | 62.66 |

**Sample: 44307-4, Top Section**

| Diameter, in. | Thickness, in. | Mass, g | Density, pcf |
|---|---|---|---|
| 1.995 | 1.033 | 51.643 | 60.80 |
| 2.000 | 1.037 | 51.656 | 60.28 |
| 1.999 | 1.038 | 51.638 | 60.26 |
| 2.000 | 1.040 | 51.624 | 60.07 |
| 2.000 | 1.038 | 51.642 | 60.20 |
| 2.004 | 1.040 | 51.595 | 59.79 |
| 2.005 | 1.040 | 51.561 | 59.69 |

## Table 4 44306 Solid Urethane Thermal Property Determinations

Interface Characteristics: 1-2

| Data Set 1 | | | | Data Set 2 | | | | Data Set 3 | | | | Data Set 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K | Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K | Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K | Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K |
| 25 | 0.1351 | 0.1570 | 0.8604 | 25 | 0.1221 | 0.1254 | 0.9738 | 25 | 0.1299 | 0.1403 | 0.9262 | 25 | 0.1330 | 0.1484 | 0.8959 |
| 40 | 0.1170 | 0.1026 | 1.141 | 40 | 0.1379 | 0.1419 | 0.9722 | 40 | 0.1374 | 0.1402 | 0.9800 | 40 | 0.1377 | 0.1397 | 0.9854 |
| 50 | 0.1329 | 0.1200 | 1.108 | 50 | 0.1379 | 0.1298 | 1.062 | 50 | 0.1408 | 0.1363 | 1.033 | 50 | 0.1409 | 0.1362 | 1.035 |
| 60 | 0.1399 | 0.1235 | 1.133 | 60 | 0.1442 | 0.1312 | 1.100 | 60 | 0.1453 | 0.1327 | 1.095 | 60 | 0.1456 | 0.1338 | 1.088 |
| 70 | 0.1433 | 0.1205 | 1.190 | 70 | 0.1494 | 0.1301 | 1.148 | 70 | 0.1488 | 0.1298 | 1.146 | 70 | 0.1496 | 0.1310 | 1.143 |
| 80 | 0.1474 | 0.1173 | 1.256 | 80 | 0.1524 | 0.1255 | 1.214 | 80 | 0.1536 | 0.1271 | 1.208 | 80 | 0.1526 | 0.1265 | 1.206 |
| 90 | 0.1515 | 0.1156 | 1.310 | 90 | 0.1608 | 0.1336 | 1.203 | 90 | 0.1618 | 0.1374 | 1.177 | 90 | 0.1616 | 0.1363 | 1.186 |

Interface Characteristics: 3-4

| Data Set 1 | | | | Data Set 2 | | | | Data Set 3 | | | | Data Set 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K | Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K | Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K | Temp, °C | TC, W/mK | TD, mm$^2$/s | SH, MJ/m$^3$K |
| 25 | 0.1255 | 0.1364 | 0.92 | 25 | 0.1373 | 0.1601 | 0.8581 | 25 | 0.1383 | 0.1636 | 0.8453 | 25 | 0.1382 | 0.1634 | 0.8457 |
| 40 | 0.1295 | 0.1261 | 1.027 | 40 | 0.1452 | 0.1590 | 0.913 | 40 | 0.1387 | 0.1429 | 0.9711 | 40 | 0.1368 | 0.1377 | 0.9939 |
| 50 | 0.1396 | 0.1360 | 1.027 | 50 | 0.1415 | 0.1345 | 1.052 | 50 | 0.1407 | 0.1351 | 1.041 | 50 | 0.1411 | 0.1327 | 1.063 |
| 60 | 0.1379 | 0.1192 | 1.156 | 60 | 0.1432 | 0.1296 | 1.105 | 60 | 0.1450 | 0.1314 | 1.103 | 60 | 0.1451 | 0.1326 | 1.095 |
| 70 | 0.1365 | 0.1072 | 1.273 | 70 | 0.1461 | 0.1247 | 1.172 | 70 | 0.1490 | 0.1290 | 1.155 | 70 | 0.1493 | 0.1297 | 1.151 |
| 80 | 0.1471 | 0.1146 | 1.273 | 80 | 0.1480 | 0.1170 | 1.265 | 80 | 0.1528 | 0.1252 | 1.220 | 80 | 0.1537 | 0.1271 | 1.210 |
| 90 | 0.1525 | 0.1167 | 1.307 | 90 | 0.1564 | 0.1216 | 1.286 | 90 | 0.1606 | 0.1330 | 1.208 | 90 | 0.1616 | 0.1344 | 1.203 |

### Average of measurements

| Average: | Density, pcf | | Thermal Conductivity, W/mK | | Thermal Diffusivity, mm$^2$/s | | Specific Heat, MJ/m$^3$K | |
|---|---|---|---|---|---|---|---|---|
| Temp, °C | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper |
| 25 | 65.03 | 63.79 | 0.130 | 0.135 | 0.143 | 0.156 | 0.914 | 0.867 |
| 40 | 64.41 | 63.43 | 0.133 | 0.138 | 0.131 | 0.141 | 1.020 | 0.976 |
| 50 | 64.63 | 63.50 | 0.138 | 0.141 | 0.131 | 0.135 | 1.060 | 1.046 |
| 60 | 64.51 | 63.38 | 0.144 | 0.143 | 0.130 | 0.128 | 1.104 | 1.115 |
| 70 | 64.37 | 63.17 | 0.148 | 0.145 | 0.128 | 0.123 | 1.157 | 1.188 |
| 80 | 64.28 | 63.09 | 0.152 | 0.150 | 0.124 | 0.121 | 1.221 | 1.242 |
| 90 | 64.23 | 63.03 | 0.159 | 0.158 | 0.131 | 0.126 | 1.219 | 1.251 |

## Table 5 44307 Solid Urethane Thermal Property Determinations

Interface Characteristics: 1-2

| Data Set 1 | | | | Data Set 2 | | | | Data Set 3 | | | | Data Set 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ | Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ | Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ | Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ |
| 25 | 0.1321 | 0.1698 | 0.7782 | 25 | 0.1323 | 0.1441 | 0.9183 | 25 | 0.1257 | 0.1256 | 1.001 | 25 | 0.1334 | 0.1488 | 0.8965 |
| 40 | 0.1370 | 0.1408 | 0.9731 | 40 | 0.1470 | 0.1579 | 0.9308 | 40 | 0.1407 | 0.1423 | 0.9887 | 40 | 0.1397 | 0.1402 | 0.9966 |
| 50 | 0.1415 | 0.1374 | 1.030 | 50 | 0.1448 | 0.1400 | 1.034 | 50 | 0.1436 | 0.1368 | 1.050 | 50 | 0.1431 | 0.1364 | 1.049 |
| 60 | 0.1404 | 0.1207 | 1.163 | 60 | 0.1461 | 0.1318 | 1.108 | 60 | 0.1471 | 0.1339 | 1.099 | 60 | 0.1365 | 0.1104 | 1.237 |
| 70 | 0.1412 | 0.1125 | 1.255 | 70 | 0.1495 | 0.1274 | 1.174 | 70 | 0.1517 | 0.1320 | 1.149 | 70 | 0.1526 | 0.1328 | 1.149 |
| 80 | 0.1397 | 0.0963 | 1.450 | 80 | 0.1495 | 0.1181 | 1.266 | 80 | 0.1550 | 0.1278 | 1.213 | 80 | 0.1558 | 0.1289 | 1.209 |
| 90 | 0.1523 | 0.1136 | 1.341 | 90 | 0.1532 | 0.1165 | 1.316 | 90 | 0.1613 | 0.1316 | 1.225 | 90 | 0.1624 | 0.1338 | 1.213 |

Interface Characteristics: 3-4

| Data Set 1 | | | | Data Set 2 | | | | Data Set 3 | | | | Data Set 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ | Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ | Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ | Temp, °C | TC, W/mK | TD, $mm^2/s$ | SH, $MJ/m^3K$ |
| 25 | 0.1230 | 0.1347 | 0.9133 | 25 | 0.1264 | 0.1425 | 0.8867 | 25 | 0.1270 | 0.1441 | 0.8813 | 25 | 0.1280 | 0.1464 | 0.8738 |
| 40 | 0.1263 | 0.1229 | 1.028 | 40 | 0.1314 | 0.1321 | 0.9947 | 40 | 0.1330 | 0.1363 | 0.9753 | 40 | 0.1337 | 0.1366 | 0.9786 |
| 50 | 0.1362 | 0.1352 | 1.007 | 50 | 0.1390 | 0.1383 | 1.005 | 50 | 0.1376 | 0.1356 | 1.015 | 50 | 0.1377 | 0.1349 | 1.021 |
| 60 | 0.1363 | 0.1223 | 1.114 | 60 | 0.1403 | 0.1302 | 1.078 | 60 | 0.1417 | 0.1335 | 1.062 | 60 | 0.1421 | 0.1330 | 1.068 |
| 70 | 0.1505 | 0.1398 | 1.076 | 70 | 0.1457 | 0.1304 | 1.117 | 70 | 0.1450 | 0.1292 | 1.122 | 70 | 0.1448 | 0.1280 | 1.132 |
| 80 | 0.1369 | 0.1049 | 1.306 | 80 | 0.1449 | 0.1198 | 1.210 | 80 | 0.1483 | 0.1269 | 1.169 | 80 | 0.1495 | 0.1292 | 1.157 |
| 90 | 0.1501 | 0.1188 | 1.264 | 90 | 0.1504 | 0.1188 | 1.265 | 90 | 0.1549 | 0.1286 | 1.205 | 90 | 0.1567 | 0.1328 | 1.180 |

### Average of measurements

| Average: | Density, pcf | | Thermal Conductivity, W/mK | | Thermal Diffusivity, $mm^2/s$ | | Specific Heat, $MJ/m^3K$ | |
|---|---|---|---|---|---|---|---|---|
| Temp, °C | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper |
| 25 | 65.85 | 62.24 | 0.131 | 0.126 | 0.147 | 0.142 | 0.899 | 0.889 |
| 40 | 65.50 | 61.77 | 0.141 | 0.131 | 0.145 | 0.132 | 0.972 | 0.994 |
| 50 | 65.48 | 61.81 | 0.143 | 0.138 | 0.138 | 0.136 | 1.041 | 1.012 |
| 60 | 65.29 | 61.65 | 0.143 | 0.140 | 0.124 | 0.130 | 1.152 | 1.081 |
| 70 | 65.22 | 61.63 | 0.149 | 0.147 | 0.126 | 0.132 | 1.182 | 1.112 |
| 80 | 64.91 | 61.28 | 0.150 | 0.145 | 0.118 | 0.120 | 1.285 | 1.211 |
| 90 | 64.87 | 61.18 | 0.157 | 0.153 | 0.124 | 0.125 | 1.274 | 1.229 |

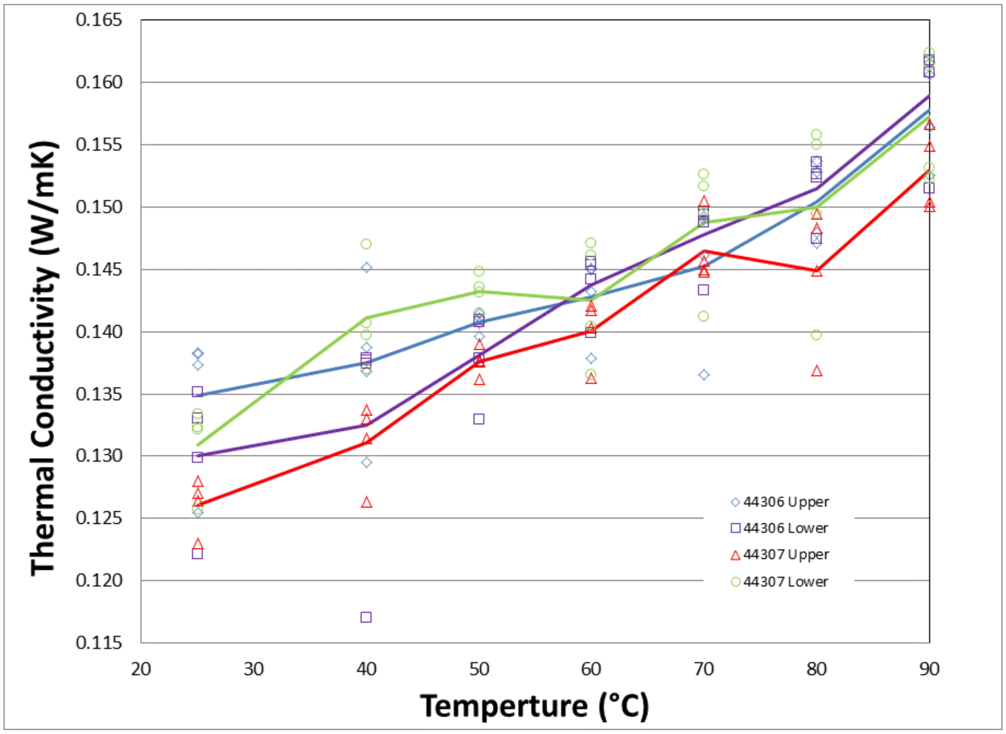


**Figure 9** Thermal conductivity vs temperature, solid urethane

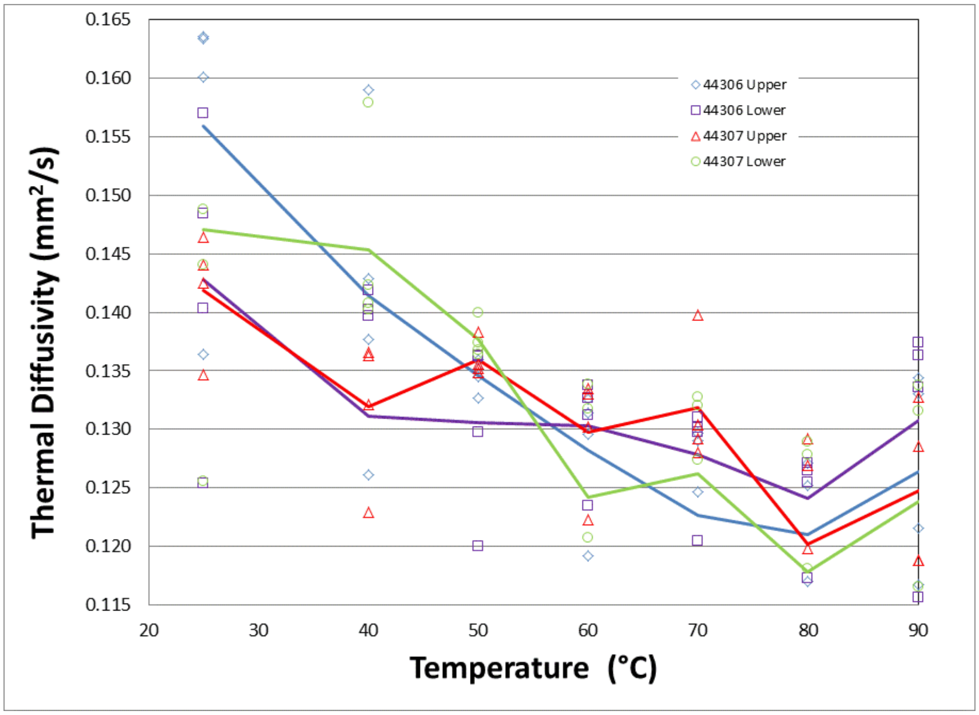


**Figure 10** Thermal diffusivity vs temperature, solid urethane

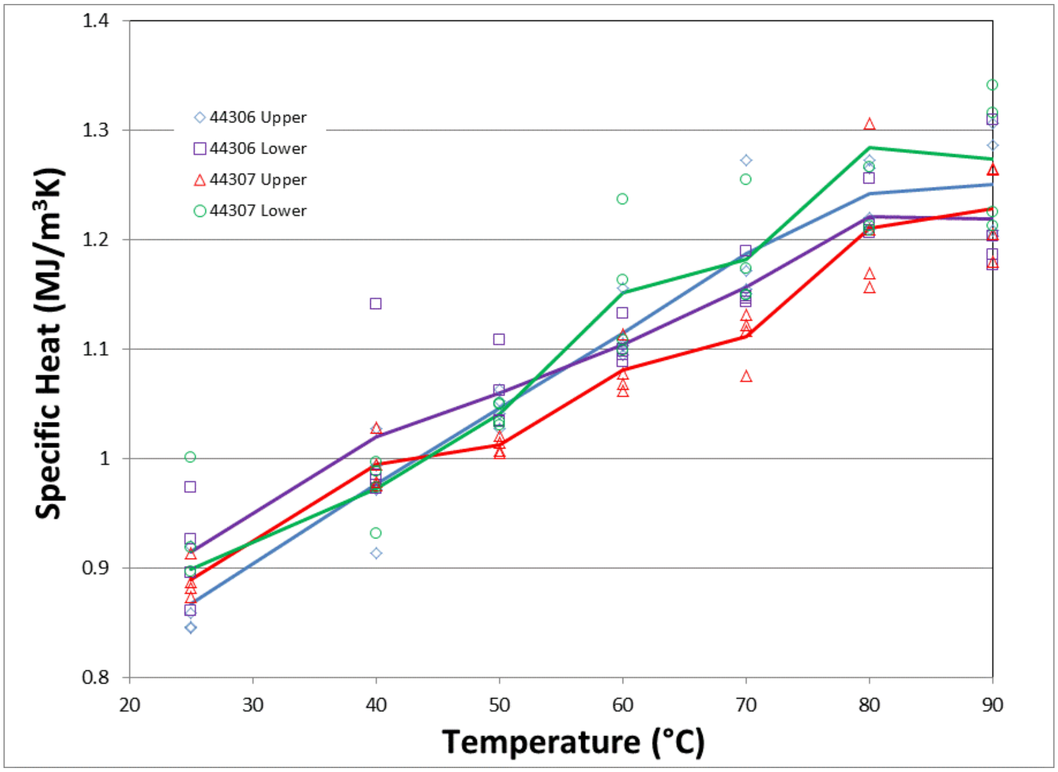


**Figure 11** **Specific heat vs temperature, solid urethane**

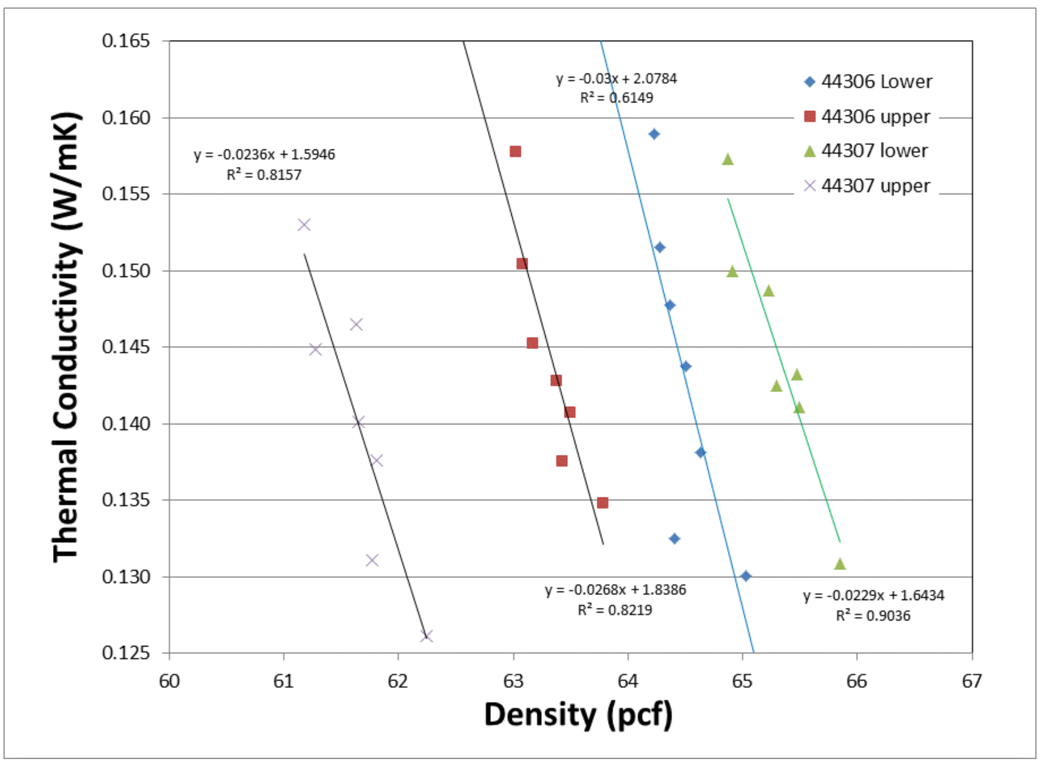


**Figure 12** **Thermal conductivity versus density, solid urethane**

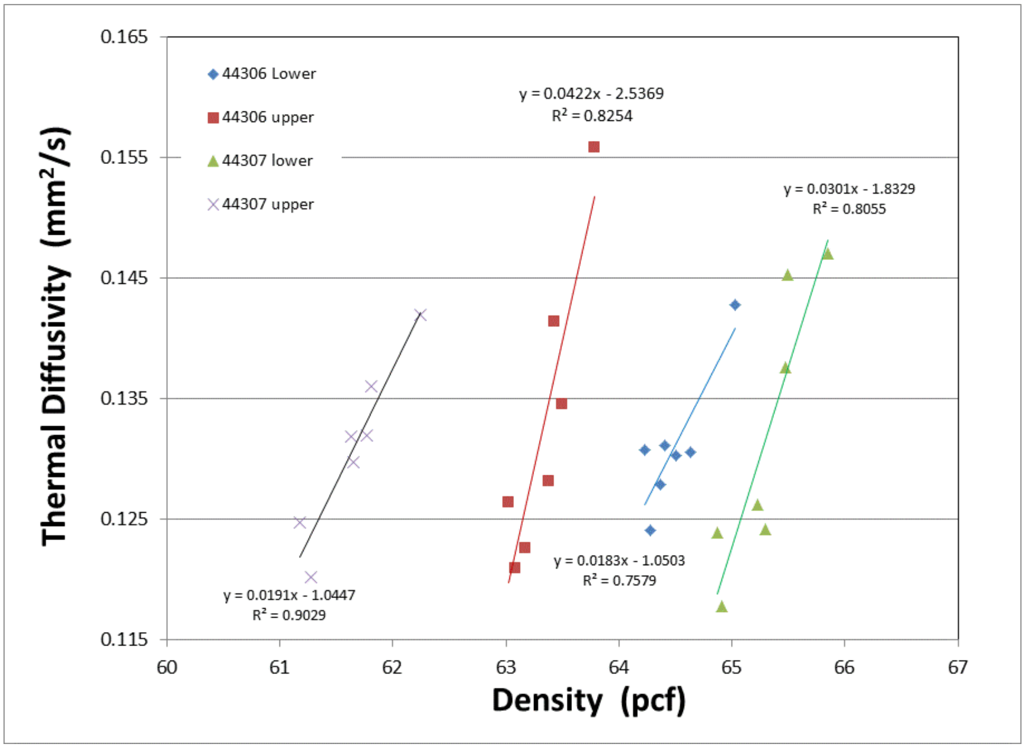


**Figure 13 Thermal diffusivity versus density, solid urethane**

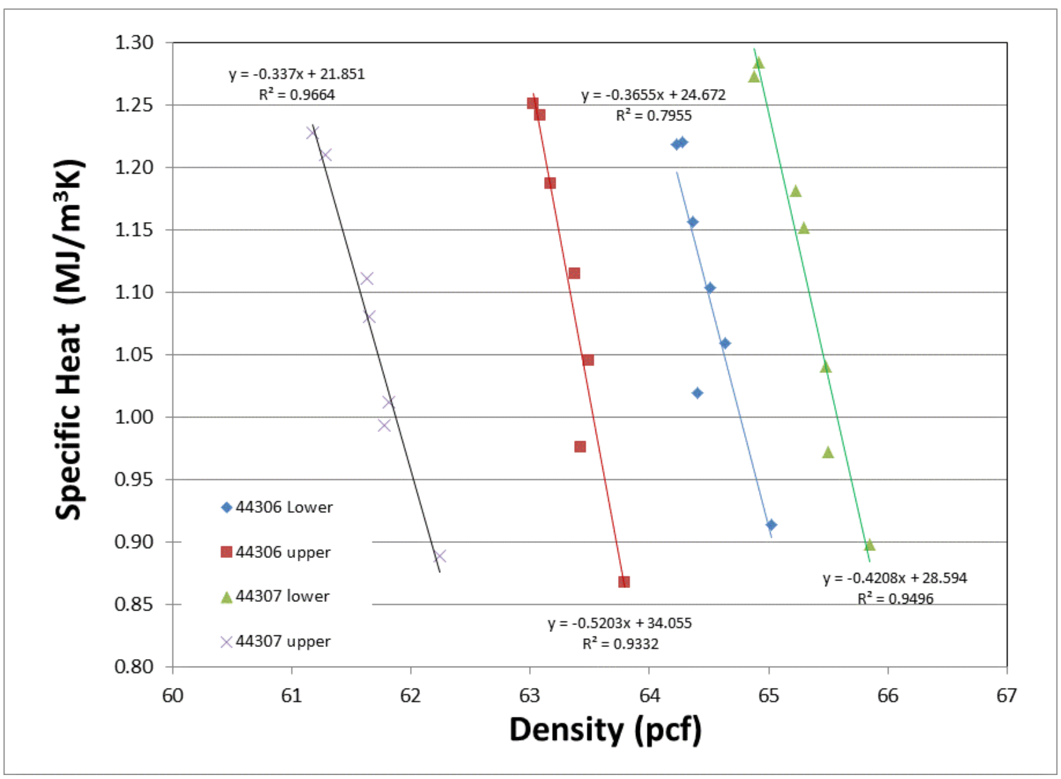

**Figure 14** **Specific Heat versus density, solid urethane**

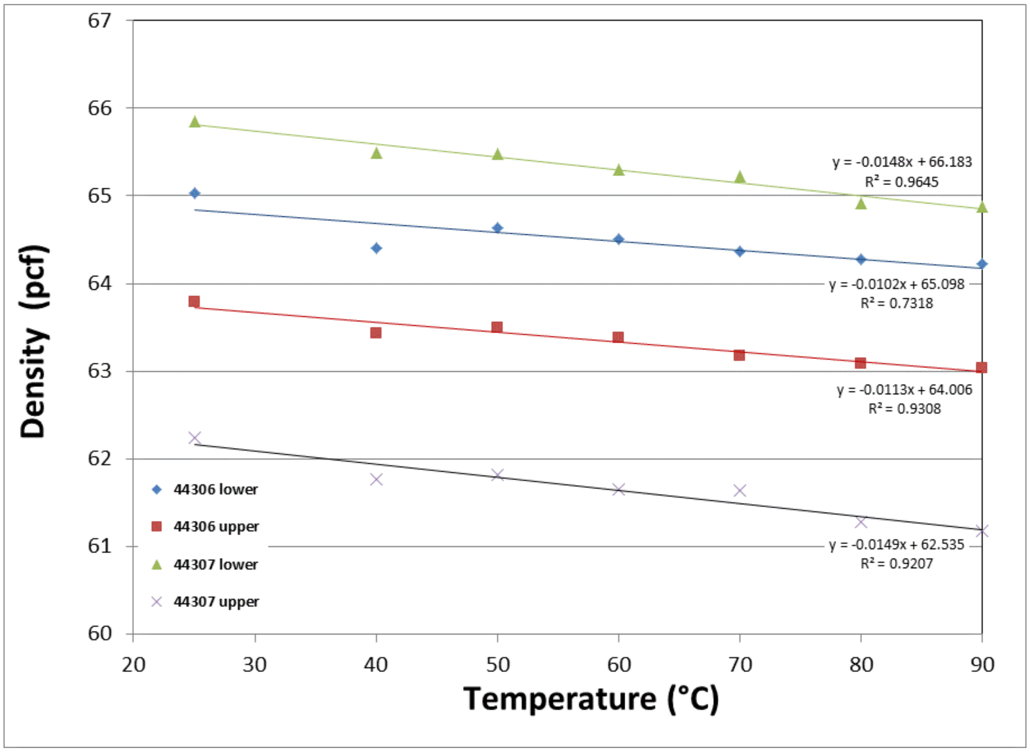


**Figure 15** **Density versus temperature, solid urethane**

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