MHSMP-80-63

# SELECTED PHYSICAL AND THERMAL PROPERTIES OF VARIOUS FORMULATIONS OF SILICONE POTTING COMPOUNDS

Gary L. Flowers
Bill D. Faubion
Jackie L. Montague
Susan T. Switzer



**November 1980**

**Process Development**
**Endeavor No. 102**

Mason & Hanger-Silas Mason Co., Inc.
Pantex Plant

P. O. BOX 30020
AMARILLO, TEXAS 79177
806-335-1581

OPERATED FOR THE
Department of Energy
UNDER
U. S. GOVERNMENT CONTRACT DE-AC04-76DP-00487

---

## NOTICE

# SELECTED PHYSICAL AND THERMAL PROPERTIES OF VARIOUS FORMULATIONS OF SILICONE POTTING COMPOUNDS

Gary L. Flowers
Billy D. Faubion
Jackie L. Montague
Susan T. Switzer



NOVEMBER 1980

Process Development
Endeavor No. 102

## INTRODUCTION

When Dow Corning discontinued production of several of their addition cured silicone potting compounds used by the DOE complex, it became necessary to develop alternate or substitute materials. This task was undertaken jointly by the Lawrence Livermore National Laboratory (LLNL) and Pantex. Several substitutes were developed and tested at both facilities. Much of this work has been reported previously(*1,2,3,4,5,6,7*). This report deals with some of the physical and thermal properties of many of these substitutes as well as some of the starting materials.

These substitutes were originally developed as replacements for 93-119, 93-120, 93-122 and mixtures of 93-119/93-120 and 93-119/93-122[a]. These substitutes are based on combining various quantities of any or all of six raw materials. These materials include:

Sylgard 186[a] - Silicone dioxide filled, high viscosity, slow curing, high strength, two part RTV.

Sylgard 184[a] - Medium viscosity, slow curing, high strength, two part RTV.

Q3-6527
Dielectric Gel[a] - Low viscosity, very slow curing, very low strength, two part RTV.

[a]*Product of Dow Corning, Midland, Michigan*

Q3-6559 Accelerator[a] - Low viscosity, vinyl terminated polydimethylsiloxane fluid containing a large concentration of a platinum catalyst.

DC-1107[a] - Low viscosity, silane hydrogen terminated polydimethylsiloxane fluid used as an accelerator.

Cabosil MS-75[b] - Silicon dioxide filler.

For this particular study, 19 formulations were selected. They include raw material only formulations as well as formulations of products currently in use by the DOE and products considered for future use by the DOE. The test data reported here are comprised of the following categories:

PHYSICAL PROPERTIES

Disk or punch shear strength
Lap shear strength
Butt tensile strength
Compressive strength
Bulk tensile strength
Durometer hardness
Dynamic shear modulus
Density
Crosslink density

THERMAL PROPERTIES

Coefficient of thermal expansion
Thermal conductivity
Specific heat
Thermal diffusivity

All samples were prepared and cured at 25 C. Unless otherwise stated, all samples were tested at 25 C after a minimum cure time of 30 days.

[a] *Product of Dow Corning, Midland, Michigan*

[b] *Product of Cabot Corporation*

| Material Number | Description* | 10-minute Viscosity (Pa·s) | Gel Time (minutes) | Comments | "A" Component | "B" Component |
|---|---|---|---|---|---|---|
| 1 | APC 2.5 | 2.5 | 1 - 97<br>1A - 140<br>1B - 67 | Based on low viscosity lots of Sylgard 184 and Dielectric Gel | Sylgard 184A (Lot 89) - 100 pbw**<br>Dielectric Gel A (Lot 31) - 5 pbw<br>Accelerator 1 - 7 pbw<br>1A - 4 pbw<br>1B - 10 pbw | Sylgard 184B (Lot 89) - 10 pbw<br>Dielectric Gel B (Lot 31) - 5 pbw |
| 2 | APC 2.5 | 2.5 | 2 - 93<br>2A - 121<br>2B - 61 | Based on high viscosity lots of Sylgard 184 and Dielectric Gel | Sylgard 184A (Lot 36) - 100 pbw<br>Dielectric Gel A (Lot 38) - 5 pbw<br>Accelerator 2 - 8 pbw<br>2A - 4 pbw<br>2B - 10 pbw | Sylgard 184B (Lot 36) - 10 pbw<br>Dielectric Gel B (Lot 38) - 5 pbw |
| 3 | APC 2.5 | 3.0 | 79 | | Sylgard 184A (Lot 36) - 100 pbw<br>Dielectric Gel A (Lot 31) - 2 pbw | Sylgard 184B (Lot 36) - 10 pbw<br>Dielectric Gel B (Lot 36) - 2 pbw<br>DC-1107 - 1.5 pbw |
| 4 | APC 2.5 | 3.3 | 72 | | Sylgard 186A (Lot 47) - 100 pbw<br>Dielectric Gel A (Lot 31) - 50 pbw | Sylgard 186 B (Lot 47) - 10 pbw<br>Dielectric Gel B (Lot 31) - 50 pbw<br>DC-1107 - 1.25 pbw |
| 5 | APC 5.0 | 5.6 | 91 | | Sylgard 186A (Lot 64) - 37 pbw<br>Sylgard 184A (Lot 36) - 63 pbw<br>Accelerator - 4 pbw | Sylgard 186B (Lot 64) - 3.7 pbw<br>Sylgard 184B (Lot 36) - 6.3 pbw |
| 6 | APC 10.0 | 9.4 | 85 | Evaluates maximum amount of Sylgard 184 in 184/186 blend | Sylgard 186A (Lot 64) - 52 pbw<br>Sylgard 184A (Lot 89) - 48 pbw<br>Accelerator - 4 pbw | Sylgard 186B (Lot 64) - 5.2 pbw<br>Sylgard 184B (Lot 89) - 4.8 pbw |
| 7 | APC 10.0 | 10.3 | 88 | Evaluates minimum amount of Sylgard 184 in 184/186 blend | Sylgard 186A (Lot 52) - 63 pbw<br>Sylgard 184A (Lot 36) - 37 pbw<br>Accelerator - 4 pbw | Sylgard 186B (Lot 52) - 6.3 pbw<br>Sylgard 184B (Lot 36) - 3.7 pbw |
| 8 | APC 10.0 | Variable | Variable | Hydrogen bonding of Cabosil causes viscosity decrease and gel time change as material absorbs atmospheric water. Not suitable for production use. | Sylgard 184A (Lot 36) - 100 pbw<br>Accelerator - 3 pbw<br>Cabosil - 6.25 pbw | Sylgard 184B (Lot 36) - 10 pbw |

**APC XXX is an identifier assigned to the material by LLNL and represents "Addition Cured Potting Compound" and XXX is the nominal viscosity in Pa·s. Sylgard is registered trademark of Dow Corning.*

***pbw - parts by weight*

| Material Number | Description* | 10-minute Viscosity (Pa·s) | Gel Time (minutes) | Comments | "A" Component | "B" Component |
|---|---|---|---|---|---|---|
| 9 | APC 10.0 | 10.3 | 108 | | Sylgard 186A (Lot 64) - 53 pbw<br>Sylgard 184A (Lot 36) - 47 pbw | Sylgard 186B (Lot 64) - 5.3 pbw<br>Sylgard 184B (Lot 36) - 4.7 pbw<br>DC-1107 - 0.3 pbw |
| 10 | APC 10.0 | 12.0 | 97 | | Sylgard 186A (Lot 47) - 85 pbw<br>Dielectric Gel A (Lot 31) - 15 pbw | Sylgard 186B (Lot 47) - 8.5 pbw<br>Dielectric Gel B (Lot 31) - 15 pbw<br>DC-1107 - 0.34 pbw |
| 11 | APC 300 | N/A | N/A | | Sylgard 186A (Lot 64) - 100 pbw<br>Accelerator - 10 pbw<br>Cabosil MS-75 - 3 pbw | Sylgard 186B (Lot 64) - 10 pbw<br>DC-1107 - 0.15 pbw |
| 12 | APC 300 | N/A | N/A | | Sylgard 184A (Lot 31) - 100 pbw<br>Accelerator - 5 pbw<br>Cabosil MS-75 - 9.653 pbw | Sylgard 184B (Lot 31) - 10 pbw<br>DC-1107 - 1.2 pbw |
| 13 | APC 300 | N/A | N/A | | Dielectric Gel A (Lot 31) - 100 pbw<br>Accelerator - 5 pbw<br>Cabosil MS-75 - 6 pbw | Dielectric Gel B (Lot 31) - 100 pbw<br>DC-1107 - 3 pbw<br>Cabosil MS-75 - 6 pbw |
| 14 | Accelerated Sylgard 184 | 3.9 | 80 | | Sylgard 184A (Lot 31) - 100 pbw<br>Accelerator - 5 pbw | Sylgard 184B (Lot 31) - 10 pbw |
| 15 | Sylgard 184 | 3.1 | Est. 10 | High viscosity lot of Sylgard 184 | Sylgard 184A (Lot 31) - 100 pbw | Sylgard 184B (Lot 31) - 10 pbw |
| 16 | Sylgard 184 | 2.0 | 243 | Low viscosity lot of Sylgard 184 | Sylgard 184A (Lot 36) - 100 pbw | Sylgard 184B (Lot 36) - 10 pbw |
| 17 | Sylgard 186 | 46.0 | N/A | High viscosity lot of Sylgard 186 | Sylgard 186A (Lot 47) - 100 pbw | Sylgard 186B (Lot 47) - 10 pbw |
| 18 | Sylgard 186 | 41.0 | N/A | Low viscosity lot of Sylgard 186 | Sylgard 186A (Lot 64) - 100 pbw | Sylgard 186B (Lot 64) - 10 pbw |
| 19 | APC 1.0 | N/A | 19 | Initial viscosity approximately 0.2 Pa·s | Dielectric Gel A (Lot 31) - 50 pbw<br>Accelerator - 10 pbw | Dielectric Gel B (Lot 31) - 50 pbw<br>DC-1107 - 1.03 pbw |

**APC XXX is an identifier assigned to the material by LLNL and represents "Addition Cured Potting Compound" and XXX is the nominal viscosity in Pa·s. Sylgard is registered trademark of Dow Corning.*

***pbw - parts by weight*

## *Physical Properties*

### DISC OR PUNCH SHEAR STRENGTH

The punch shear test (similar to ASTM 0732) employed a 1.59 mm thick test sample located between a punch and die. The punch sheared the sample into the die at a rate of 1.27 mm/min during testing.

| Material Number | Average (KPa) | Standard Deviation (KPa) | Material Number | Average (KPa) | Standard Deviation (KPa) |
|---|---|---|---|---|---|
| 1 | 1100 | 85 | 11 | 2314 | 135 |
| 2 | 1178 | 34 | 12 | 3057 | 157 |
| 3 | 1514 | 53 | 13 | 938 | 43 |
| 4 | 1381 | 36 | 14 | 1782 | 57 |
| 5 | 1553 | 37 | 15 | 1789 | 136 |
| 6 | 1774 | 91 | 16 | 1462 | 22 |
| 7 | 1831 | 46 | 17 | 2292 | 54 |
| 8 | 2174 | 62 | 18 | 1941 | 49 |
| 9 | 1602 | 35 | 19 | - | - |
| 10 | 1760 | 44 | | | |

*NOTE: Sample Size n = 5*

### LAP SHEAR STRENGTH

The lap shear test (ASTM D-1002) employed two aluminum panels (25.4 mm x 101.6 mm) which overlapped 12.7 mm with an adhesive thickness of 0.127 mm. These assemblies were tested in shear at a rate of 1.27 mm/min.

| Material Number | Average (KPa) | Standard Deviation (KPa) | Material Number | Average (KPa) | Standard Deviation (KPa) |
|---|---|---|---|---|---|
| 1 | 167 | 16 | 11 | - | - |
| 2 | - | - | 12 | - | - |
| 3 | 322 | 72 | 13 | - | - |
| 4 | 157 | 26 | 14 | 329 | 51 |
| 5 | 209 | 8 | 15 | 151 | 18 |
| 6 | 192 | 20 | 16 | - | - |
| 7 | - | - | 17 | 374 | 65 |
| 8 | 363 | 66 | 18 | - | - |
| 9 | 357 | 93 | 19 | - | - |
| 10 | 475 | 92 | | | |

*NOTE: Sample Size n = 5*

## BUTT TENSILE STRENGTH

The butt tensile test (ASTM D-2094) employed two aluminum cylinders (28.66 mm diameter x 38.1 mm high) butt bonded with an 0.127 mm thick adhesive bond. These samples were then tested to failure in tension at a rate of 1.27 mm/min.

| Material Number | Average (KPa) | Standard Deviation (KPa) | Material Number | Average (KPa) | Standard Deviation (KPa) |
|---|---|---|---|---|---|
| 1 | 1293 | 163 | 11 | - | - |
| 2 | - | - | 12 | - | - |
| 3 | 1666 | 424 | 13 | - | - |
| 4 | 1708 | 189 | 14 | 2508 | 270 |
| 5 | 946 | 80 | 15 | 1329 | 140 |
| 6 | 971 | 90 | 16 | 3575 | - |
| 7 | - | - | 17 | 3575 | 345 |
| 8 | 1923 | 174 | 18 | - | - |
| 9 | 3178 | 451 | 19 | - | - |
| 10 | 3026 | 486 | | | |

*NOTE: Sample Size n = 5*

## COMPRESSIVE STRENGTH

The compressive strength test was performed on cylindrical test specimens 20.27 mm diameter x 25.4 mm high. These were tested to failure in compression at a compression rate of 2.5 mm/min.

| Material Number | Average (KPa) | Standard Deviation (KPa) | Material Number | Average (KPa) | Standard Deviation (KPa) |
|---|---|---|---|---|---|
| 1 | 23.1 | 10.3 | 11 | - | - |
| 2 | 33.3 | 13.4 | 12 | - | - |
| 3 | 42.9 | 5.3 | 13 | - | - |
| 4 | 73.2 | 20.4 | 14 | 45.7 | 5.6 |
| 5 | 76.8 | 7.9 | 15 | 58.3 | 7.5 |
| 6 | 76.5 | 13.0 | 16 | 59.4 | 6.7 |
| 7 | 200.0 | 32.9 | 17 | 276.0 | - |
| 8 | 7.9 | 1.5 | 18 | 276.0 | - |
| 9 | 104.1 | 13.7 | 19 | 1.0 | 0.49 |
| 10 | 182.2 | 27.8 | | | |

*NOTE: Sample Size n - 5*

## DUROMETER HARDNESS

Durometer hardness was determined via a Shore A2 durometer according to ASTM D-1706. The samples were 25.4 mm x 25.4 mm x 6.35 mm patties.

| Material Number | Average 24 Hours | 30 Days | Material Number | Average 24 Hours | 30 Days |
|---|---|---|---|---|---|
| 1 | 37.6 | 49.5 | 11 | 31.0 | 37.0 |
| 2 | 31.2 | 44.5 | 12 | 44.7 | 54.5 |
| 3 | 31.3 | 44.0 | 13 | 35.5 | 45.0 |
| 4 | 29.7 | 38.5 | 14 | 33.6 | 49.0 |
| 5 | 26.9 | 36.5 | 15 | 34.3 | 46.0 |
| 6 | 29.1 | 41.0 | 16 | 29.7 | 41.5 |
| 7 | 28.2 | 39.0 | 17 | 24.4 | 40.0 |
| 8 | 40.6 | 52.0 | 18 | 11.0 | 35.0 |
| 9 | 26.6 | 35.0 | 19 | 20.9 | 33.5 |
| 10 | 13.1 | 36.5 | | | |

## DYNAMIC SHEAR MODULUS

A Rheometrics 7200 Mechanical Spectrometer was employed for all measurements. The test specimens were 25.4 mm diameter X 5.7 mm high disks clamped under load between two parallel plates with serrated faces. The top plate oscillated clockwise/counterclockwise at a selected frequency while the lower plate (to which the load and torque transducers were attached) remained stationary. For a given sample, the following test parameters could be varied; clamping load, test temperature, oscillation frequency and maximum strain amplitude. Since the shear modulus is essentially independent of strain amplitude as long as strain amplitude is small and the material is in the linear portion of the viscoelastic curve, a small strain amplitude of 0.5% was selected. Since oscillation frequency can be changed quite readily, an automatic scan from 100 mhz to 10 hz was selected. Temperature is very time consuming to vary so three temperatures were selected: -40, 25 and 100 C. Load plays a very important part in determining modulus, i.e., as load increases, so does the modulus. Therefore, load was varied from 100 to 2000 g or 0.204 to 4.074 g/mm$^2$. Fig. 1 shows a typical modulus versus clamping load for material No. 15 tested at 1 hz.

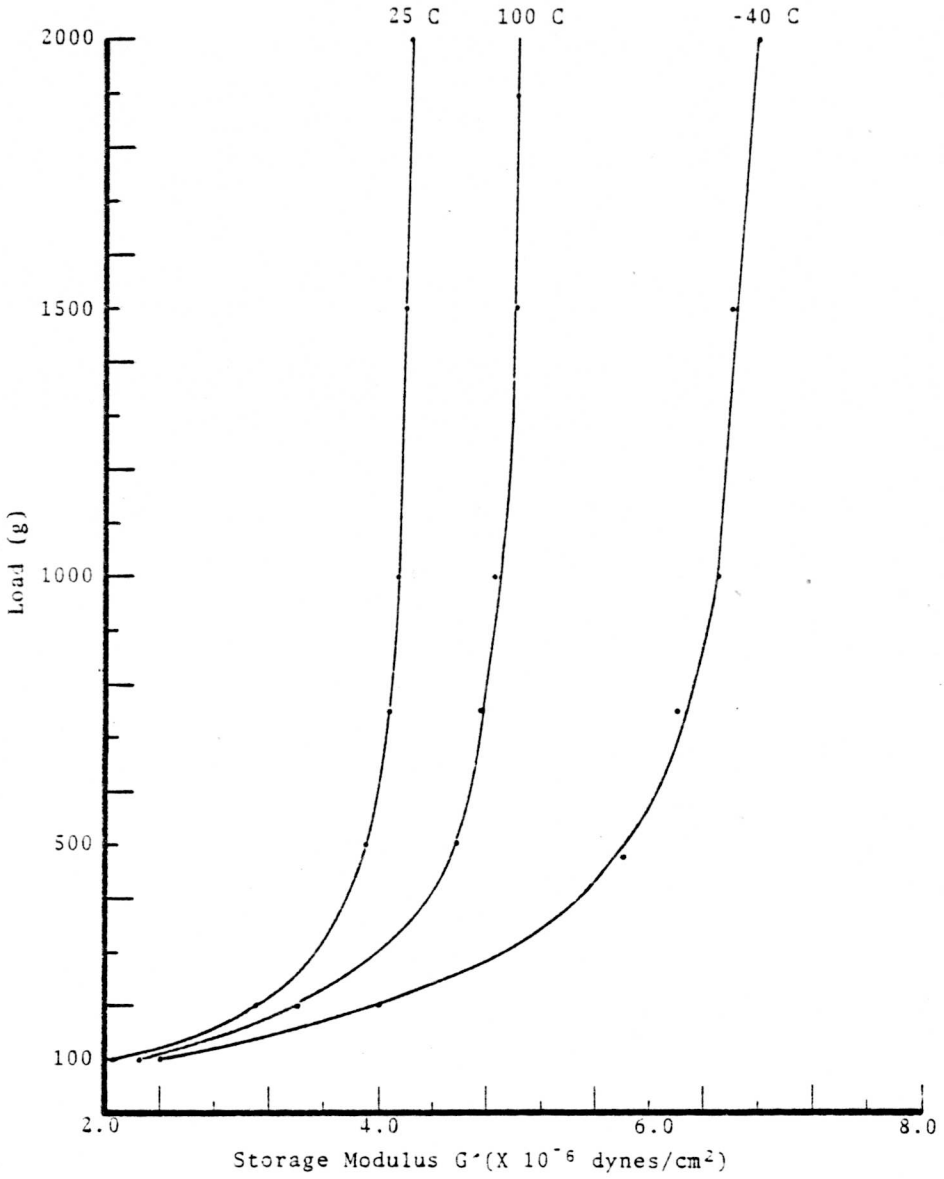


Fig. 1. Storage Modulus (G') Versus Clamping Load for Material No. 15

Modulus normally decreases rapidly above the glass transition point as the temperature increases. Therefore, several questions arose when the 100 C curve consistently had a higher modulus than either 25 or -40 C. This occurred for several materials. A special run was made on material No. 15 where a constant load of 2000 g, strain amplitude of 0.5%, and a

test frequency of 1 hz was used and the temperature was varied from -140 to 100 C. These data, shown in Fig. 2, explain why the storage modulus at 100 C was greater than the storage modulus at either 25 or -40 C.

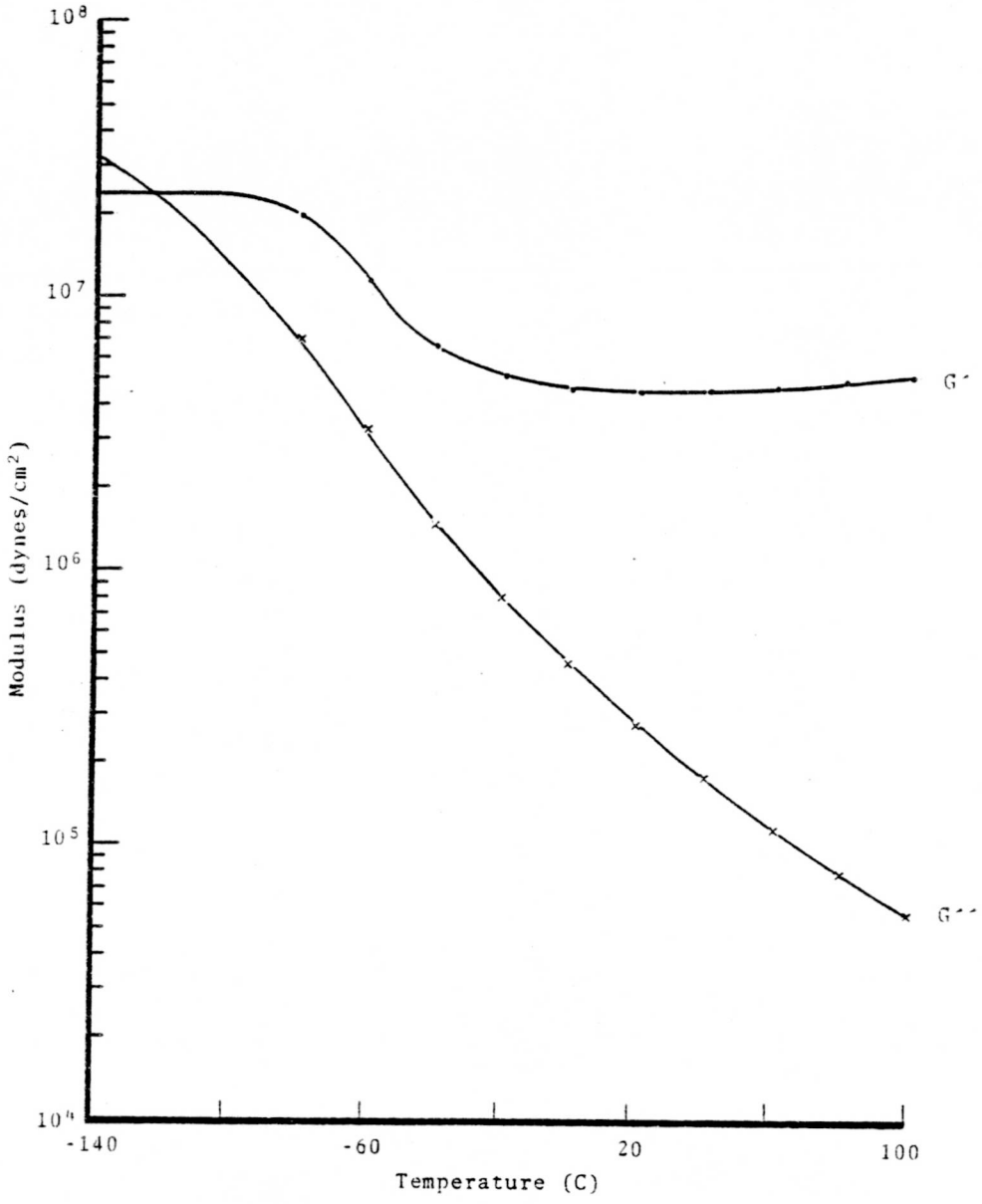


Fig. 2. Modulii Versus Temperature for Material No. 15

It was decided that for a comparison test between samples that the following parameters should be chosen; maximum strain amplitude of 0.5 percent, clamping load of 1000 g or 2.037 g/mm$^2$, test frequency of 1 hz

and a test temperature of 25 C. Under these conditions, the following data were generated. Some data were also available at these conditions except at -40 and 100 C.

| Material Number | Storage Shear Modulus $G'$ (X $10^{-6}$ dynes/cm$^2$) | | | Loss Shear Modulus $G''$ (X $10^{-4}$ dynes/cm$^2$) | | | Tan $\delta$ (X $10^2$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | -40 C | 25 C | 100 C | -40 C | 25 C | 100 C | -40 C | 25 C | 100 C |
| 1 | - | 5.07 | - | - | 14.00 | - | - | 2.60 | - |
| 1A | 5.56 | 5.05 | 6.10 | 87.70 | 16.60 | 7.17 | 15.40 | 3.30 | 1.18 |
| 1B | 5.09 | 5.02 | 6.20 | 66.00 | 13.40 | 5.46 | 13.00 | 2.60 | 0.88 |
| 2 | - | 3.75 | - | - | 3.90 | - | - | 1.00 | - |
| 2A | 3.12 | 3.59 | 4.49 | 23.40 | 4.90 | 2.63 | 7.49 | 1.36 | 0.59 |
| 2B | 3.34 | 3.78 | 4.84 | 21.30 | 4.10 | 2.83 | 6.39 | 1.07 | 0.59 |
| 3 | - | 4.07 | - | - | 6.30 | - | - | 1.60 | - |
| 4 | - | 3.35 | - | - | 3.58 | - | - | 1.12 | - |
| 5 | - | 3.17 | - | - | 7.29 | - | - | 2.31 | - |
| 6 | 3.67 | 3.80 | 4.57 | 31.60 | 10.50 | 6.79 | 8.61 | 2.88 | 1.49 |
| 7 | 3.72 | 3.91 | 4.02 | 25.00 | 9.62 | 10.90 | 6.70 | 2.47 | 2.70 |
| 8 | - | 5.88 | - | - | 14.60 | - | - | 2.48 | - |
| 9 | - | - | - | - | - | - | - | - | - |
| 10 | - | 3.89 | - | - | 7.25 | - | - | 1.86 | - |
| 11 | - | 3.57 | - | - | 17.20 | - | - | 4.82 | - |
| 12 | - | 10.20 | - | - | 59.40 | - | - | 5.83 | - |
| 13 | - | 4.91 | - | - | 5.10 | - | - | 1.04 | - |
| 14 | - | 5.09 | - | - | 2.16 | - | - | 4.25 | - |
| 15 | 6.50 | 4.35 | 4.85 | 144.50 | 2.26 | 6.77 | 22.20 | 5.21 | 1.40 |
| 16 | - | 3.22 | - | - | 6.80 | - | - | 2.11 | - |
| 17 | 4.40 | 4.40 | 4.23 | 47.70 | 18.60 | 12.10 | 10.80 | 4.41 | 2.89 |
| 18 | - | 2.92 | - | - | 15.10 | - | - | 5.17 | - |
| 19 | 2.25 | 2.90 | 3.55 | 1.79 | 0.71 | 0.68 | 0.80 | 0.24 | 0.19 |

## DENSITY

Density was measured on small samples of materials using a standard pycnometer.

| Material Number | Density (g/cm$^2$) | Material Number | Density (g/cm$^2$) |
|---|---|---|---|
| 1 | 1.031 | 11 | - |
| 2 | 1.020 | 12 | - |
| 3 | 1.026 | 13 | - |
| 4 | 1.044 | 14 | 1.036 |
| 5 | 1.051 | 15 | 1.038 |
| 6 | 1.068 | 16 | 1.024 |
| 7 | 1.075 | 17 | 1.109 |
| 8 | 1.054 | 18 | 1.105 |
| 9 | 1.067 | 19 | 0.980 |
| 10 | 1.074 | | |

## CROSSLINK DENSITY

The molecular weight between crosslinks ($M_c$) and the effective number of moles of networks crosslink per cubic centimeter ($V_c$) can be determined by a solvent swell technique employing hexane(*8,9*).

| Material Number | $M_c$ ($M_w$/crosslink) | $V_e$ (crosslink moles/cm$^3$ x $10^{-4}$) |
|---|---|---|
| 1 | 1256 | 7.96 |
| 2 | 1855 | 5.37 |
| 3 | 1825 | 5.48 |
| 4 | 4115 | 2.43 |
| 5 | 3268 | 3.06 |
| 6 | 2717 | 3.68 |
| 7 | 4184 | 2.39 |
| 8 | 1387 | 7.21 |
| 9 | 3731 | 2.68 |
| 10 | 4329 | 2.31 |
| 11 | - | - |
| 12 | - | - |
| 13 | - | - |
| 14 | 1346 | 7.43 |
| 15 | 1822 | 5.49 |
| 16 | 2141 | 4.67 |
| 17 | 4695 | 2.13 |
| 18 | 5747 | 1.74 |
| 19 | 4505 | 2.22 |

## *Thermal Properties*

### COEFFICIENT OF THERMAL EXPANSION (LINEAR)

Linear CTE measurements were made using the 940 Thermalmechanical Analyzer plug-in module for the DuPont 900 Thermal Analyzer. A 4mm diameter quartz expansion probe was used with a 5 g loading. Samples were nominally 6.35 mm diameter right circular cylinders cast from Lexan molds. The exact height of each sample was measured at ambient temperature with a micrometer. Temperature was increased from -80 to 90 C at 5 degrees/minute and the vertical sample expansion recorded. The CTE was calculated by comparing the slope of the sample curve to that of an aluminum standard. The slope was measured over a 10° temperature ranged centered at the reported temperatures. The values for the CTE of aluminum at these temperatures were taken from the American Institute of Physics Handbook, Second Edition. The CTE values reported are the average of at least four determinations with the variation given at $\pm 1\sigma$.

| | Coefficient of Thermal Expansion (μm/m - Deg C) | | | | | |
|---|---|---|---|---|---|---|
| | -23 C | | 27 C | | 77 C | |
| Material Number | Average | Standard Deviation | Average | Standard Deviation | Average | Standard Deviation |
| 1 | 314 | 13 | 344 | 13 | 346 | 15 |
| 2 | - | - | - | - | - | - |
| 3 | - | - | - | - | - | - |
| 4 | - | - | - | - | - | - |
| 5 | 379 | 14 | 325 | 6 | 329 | 2 |
| 6 | 379 | 16 | 324 | 10 | 325 | 8 |
| 7 | - | - | - | - | - | - |
| 8 | 308 | 19 | 316 | 13 | 315 | 15 |
| 9 | - | - | - | - | - | - |
| 10 | 383 | 10 | 337 | 15 | 330 | 15 |
| 11 | *a* | *a* | 377 | 4 | 390 | 16 |
| 12 | 273 | 16 | 300 | 18 | 318 | 9 |
| 13 | 380 | 20 | 318 | 1 | 331 | 2 |
| 14 | 302 | 7 | 301 | 7 | 319 | 2 |
| 15 | 291 | 18 | 322 | 18 | 353 | 12 |
| 16 | - | - | - | - | - | - |
| 17 | 302 | 1 | 289 | 6 | 332 | 15 |
| 18 | - | - | - | - | - | - |
| 19 | 347 | 5 | 316 | 10 | 370 | 16 |

*NOTE: Sample Size n = 4*

[a] *Phase transition*

## THERMAL CONDUCTIVITY

Thermal conductivity (K) was determined using a comparative method adapted for the Perkin-Elmer DSC(*10,11*). The same samples were used for both thermal conductivity and the CTE Measurements. In this method the difference in the heat flow required to maintain a 10° temperature gradient across the sample and a Teflon reference of similar dimensions is measured. Thermal conductivity is calculated using these values, the sample and reference dimensions and the thermal conductivity of the reference. Measurements were made with the DSC set at 45 C and the cold surface temperature maintained at 35 C using a button heater and temperature controller. A thin film of thermal conductive paste (Thermacote Thermal Joint Compounds, Thermallog Co., Dallas, Texas) was used to insure good thermal contact between the ends of the sample and the hot and cold plates.

| Material Number | (K) (X $10^4$ cal/cm-sec-°C) Average | Standard Deviation | Material Number | (K) (X $10^4$ cal/cm-sec-°C) Average | Standard Deviation |
|---|---|---|---|---|---|
| 1 | 5.33 | 0.01 | 11 | 5.32 | 0.01 |
| 2 | - | - | 12 | 5.27 | - |
| 3 | - | - | 13 | 5.74 | 0.05 |
| 4 | - | - | 14 | 5.48 | 0.15 |
| 5 | 5.54 | 0.07 | 15 | 5.55 | 0.07 |
| 6 | 5.57 | 0.10 | 16 | - | - |
| 7 | - | - | 17 | 5.68 | 0.09 |
| 8 | 5.52 | 0.06 | 18 | - | - |
| 9 | - | - | 19 | 5.69 | 0.07 |
| 10 | 5.48 | 0.05 | | | |

*NOTE: Sample Size n = 4*

## SPECIFIC HEAT {Cp}

Specific heat or heat capacity ($C_p$) was determined using a Perkin-Elmer DSC-1 following the standard Perkin-Elmer procedure. Specific heat was determined at both 40 and 50 C.

| Material Number | Specific Heat ($C_p$) (cal/g - deg C) 40 C Average | 40 C Standard Deviation | 50 C Average | 50 C Standard Deviation |
|---|---|---|---|---|
| 1 | 0.366 | - | 0.389 | - |
| 2 | - | - | - | - |
| 3 | - | - | - | - |
| 4 | - | - | - | - |
| 5 | 0.324 | 0.006 | 0.313 | 0.002 |
| 6 | 0.330 | 0.010 | 0.330 | 0.010 |
| 7 | - | - | - | - |
| 8 | 0.354 | 0.007 | 0.363 | 0.003 |
| 9 | - | - | - | - |
| 10 | 0.332 | 0.004 | 0.344 | 0.002 |
| 11 | 0.358 | 0.004 | 0.379 | 0.002 |
| 12 | 0.340 | 0.0005 | 0.345 | 0.003 |
| 13 | 0.370 | 0.006 | 0.383 | 0.007 |
| 14 | 0.327 | 0.002 | 0.324 | 0.003 |
| 15 | 0.388 | 0.002 | 0.386 | - |
| 16 | - | - | - | - |
| 17 | 0.340 | 0.010 | 0.350 | 0.020 |
| 18 | - | - | - | - |
| 19 | 0.480 | 0.020 | 0.491 | 0.004 |

*NOTE: Sample Size n = 4*

## THERMAL DIFFUSIVITY

Thermal diffusivity ($\alpha$) is calculated based on the following relationship:

$$\alpha = K/\delta C_p$$

where

$K$ = Thermal Conductivity
$\delta$ = Density
$C_p$ = Heat Capacity or Specific Heat

| Material Number | Thermal Diffusivity ($\alpha$)(X $10^3$ $cm^2$/sec) 45 C | Material Number | Thermal Diffusivity ($\alpha$)(X $10^3$ $cm^2$/sec) 45 C |
|---|---|---|---|
| 1 | 1.369 | 11 | - |
| 2 | - | 12 | - |
| 3 | - | 13 | - |
| 4 | - | 14 | 1.625 |
| 5 | 1.655 | 15 | 1.382 |
| 6 | 1.580 | 16 | - |
| 7 | - | 17 | 1.414 |
| 8 | 1.461 | 18 | - |
| 9 | - | 19 | 1.196 |
| 10 | 1.510 | | |

## REFERENCES


1. Flowers, G. L. and Switzer, S. T., Background Material Properties of Selected Silicone Potting Compounds and Raw Materials for Their Substitutes, MHSMP-78-18, Amarillo, Texas, 1978.

2. Flowers, G. L. and Switzer, S. T., A Substitute Potting Compound for Sylgard 93-119 Based on Sylgard 184 and Q3-6527 Dielectric Gel, MHSMP-78-23, Amarillo, Texas, 1978.

3. Flowers, G. L. and Switzer, S. T., Substitute Potting Compounds for Sylgard 93-120, MHSMP-79-37, Amarillo, Texas, 1979.

4. Clink, G. L., FT-NMR Determination of the Silane Hydrogen Content of Siloxane Pre-Polymers, MHSMP-78-45, Amarillo, Texas, 1978.

5. Clink, G. L., FT-NMR Analysis of Silane Hydrogen, Phenyl, and Vinyl Content of Several Siloxane Pre-Polymer Materials, MHSMP-79-15, Amarillo, Texas, 1979.

6. Kohn, E. and Ashcraft, R. W., High Performance Size Exclusion Chromatography (V) Molecular Characterization of Silicone Fluids and Sums by Computer Deconvolution, MHSMP-80-27, Amarillo, Texas, 1980.

7. Cady, W. E. and Buckner, A. T., Development of Alternate Silicone Potting Compounds, Vol. 1-5, Lawrence Livermore National Laboratory, UCRL-52434, Livermore, California, 1978-1980.

8. Encyclopedia of Polymer Science and Technology, Vol. 4, 331-335, Herman, F. M., Gaylord, N. G. and Biboles, N. M., Interscience Pub. John Wiley and Sons, Inc., New York, 1966.

9. Barroll II, E. M., Flandera, M. A. and Logan, J. A., A Thermodynamic Study of the Crosslinking of Methyl Silicone Rubber, Thermochimica Acta, Elsevier Pub. Co., Amsterdam, 5(1973), 415-432.

10. Baytos, J. F., Specific Heat and Thermal Conductivity of Explosives, Mixtures and Plastic-Bonded Explosives Determined Experimentally, Los Alamos National Scientific Laboratory, LA-8034-MS, New Mexico.

11. Brennan, W. P., Miller, B. and Whitewell, J. C., Thermal Conductivity Measurements with the Differential Scanning Calorimeter, J. Applied Polymer Science 12, 1800-1802, 1968.

## DISTRIBUTION

**Department of Energy - Washington, D.C.**

Caudle, R. E.

**Department of Energy - ALO**

Fredlund, R. R., Jr.
Whiteman, A. E.

**Department of Energy - AAO**

Johnson, G. W.

**Bendix Corp.**

Smith, C.

**Lawrence Livermore National Laboratory**

Brockett, C. T.
Cady, W. E.
Golopol, H.
Root, G. S.
Attn: van Dyk, A. C. (18)

**Los Alamos National Scientific Laboratory**

Daly, R. J.
DuBois, F.
Flaugh, H. L.
Fuller, J. C.
Report Library - ISD-4
Wechsler, J. J.
Yasuda, S. K.

**Mason & Hanger - Pantex**

Bailey, R. E.
Carr, B. H.
Ferranti, R.
Ihne, R. J.
Johnson, M. S.
Laseter, W. A.
Myers, L. C.
Poynor, E. D.
Slape, R. J.
Taylor, R. E.
Circulation Copy
(1) Plant Manager, PX
(2) M&H, Lexington, KY
Technical Library
File (5)
Technical Information Center (27)

**Mound Facility**

Braun, R. J.
Dichioro, J.

**Sandia National Laboratories - Albuquerque**

Arthur, B. E.
Central Technical Files
Crawford, J. C./
Anderson, D. H.
Garner, W. L. (3)

**Sandia National Laboratories - Livermore**

Aas, E. A.
Cozine, R. D.

**United Kingdom**

Long, W. S., British Embassy
For: Kirkham, J.