Ryton® PPS

Thermal Properties

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For more information and
technical assistance contact:

Chevron Phillips Chemical Company, LP
P.O. Box 3766
Houston, TX 77253-3766
1-877-798-6666

ISO 9002 and A2LA Certified

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Thermal Conductivity

Thermal conductivity was determined using the Colora Thermoconductor. The sample was placed between ground silver plates, kept at the given boiling points of two liquids by a constant supply of heat to the liquid with the higher boiling point. When steady equilibrium was attained, the liquid having the lower boiling point vaporized at a constant rate. It was condensed and then collected in a measuring vessel. The time required to distill a specified volume was measured. From a previously obtained calibration curve for similar sized discs of known thermal conductivity, the thermal resistivity and conductivity of the test sample was derived.

Table I – Thermal Conductivity of Ryton® PPS Compounds

Grade	Temp., °F	Thermal Conductivity Btu•in/hr•ft²/°F
R-4	104	2.1
	200	2.2
	333	2.4
R-4 02XT	140	1.9
	212	2.1
R-7	104	4.0
	200	4.2
	333	4.5
R-10 7006A	104	3.9
	200	3.9
	333	3.9
R-10 5002C	104	3.9
	200	3.9
	333	3.9
R-10 5004A	104	4.2
	200	4.1
	333	4.1
A-200	158	2.2
	194	2.2
	338	2.5

Specific Heat

For determination of specific heat, a sample was analyzed using a quantitative Adiabatic Calorimeter. This sample was weighed, tightly enclosed in an electrically heated gold-plated copper container, and suspended inside a massive nickel-plated and polished guard. The entire assembly was evacuated, backfilled with N_2, then cooled to a uniform temperature below the lowest mean temperature required for data. When steady conditions were obtained, a controlled rate, continuous power input was supplied to the heater on the sample container. By utilizing the output of a multi-junction differential thermopile, the power to the guard heater was automatically controlled so that the temperature of the guard was equal to the temperature of the sample. This allowed negligible heat transfer from the sample to its surroundings. From observations of the power input to the heater, a continuous record of sample temperature variation with time, a record of the sample and container enthalpy change with temperature was obtained.

The specific heat of the sample was derived from its weight, the record of the total enthalpy change with temperature and the enthalpy change for the sample container.

Table II – Specific Heat of Ryton® PPS Compounds

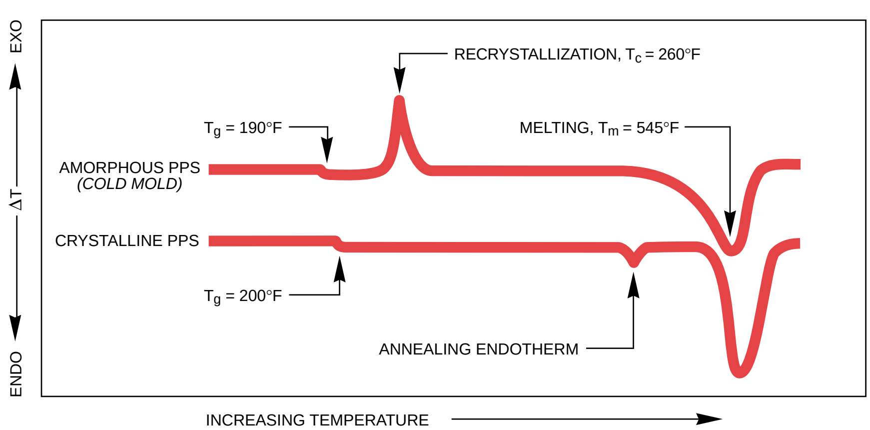
	Specific Heat, Btu/lb•°F Ryton PPS Grades			
	R-4	R-10		
Temperature, °F		7006A	5002C	5004A
32	0.125	–	–	–
104	0.247	0.192	0.185	0.190
176	0.282	0.209	0.203	0.203
248	0.311	0.228	0.220	0.227
320	0.330	0.239	0.230	0.239
392	0.344	0.249	0.239	0.248
464	0.356	0.257	0.245	0.255
536	0.392	0.406	0.413	0.385
640	0.497	–	–	–

Differential Thermal Analysis

The Differential Thermal Analysis (DTA) of molded PPS compares the increasing temperature of a test material to that of a reference material when both are heated at the same constant rate. Any change in the rate of temperature increase indicates some other change in heat energy of the material. For example, low crystallinity PPS exhibits glass transition, recrystallization and melting at the temperatures noted on the thermogram in *Figure 1*. Of course, highly crystalline PPS does not show that same recrystallization exotherm, but annealed material can exhibit a small endothermic peak slightly above the annealing temperature. In addition, highly crystalline PPS exhibits a slightly higher T_g and T_m with a more sharply defined melting range.

Crystallinity has such an important effect on the balance of PPS properties that many processors use DTA as a quality control test. Even without quantitative evaluation, the DTA thermogram can provide a qualitative indication whether the part is or is not fully crystallized.

Figure 1 – Dfferential Thermal Analysis Curves

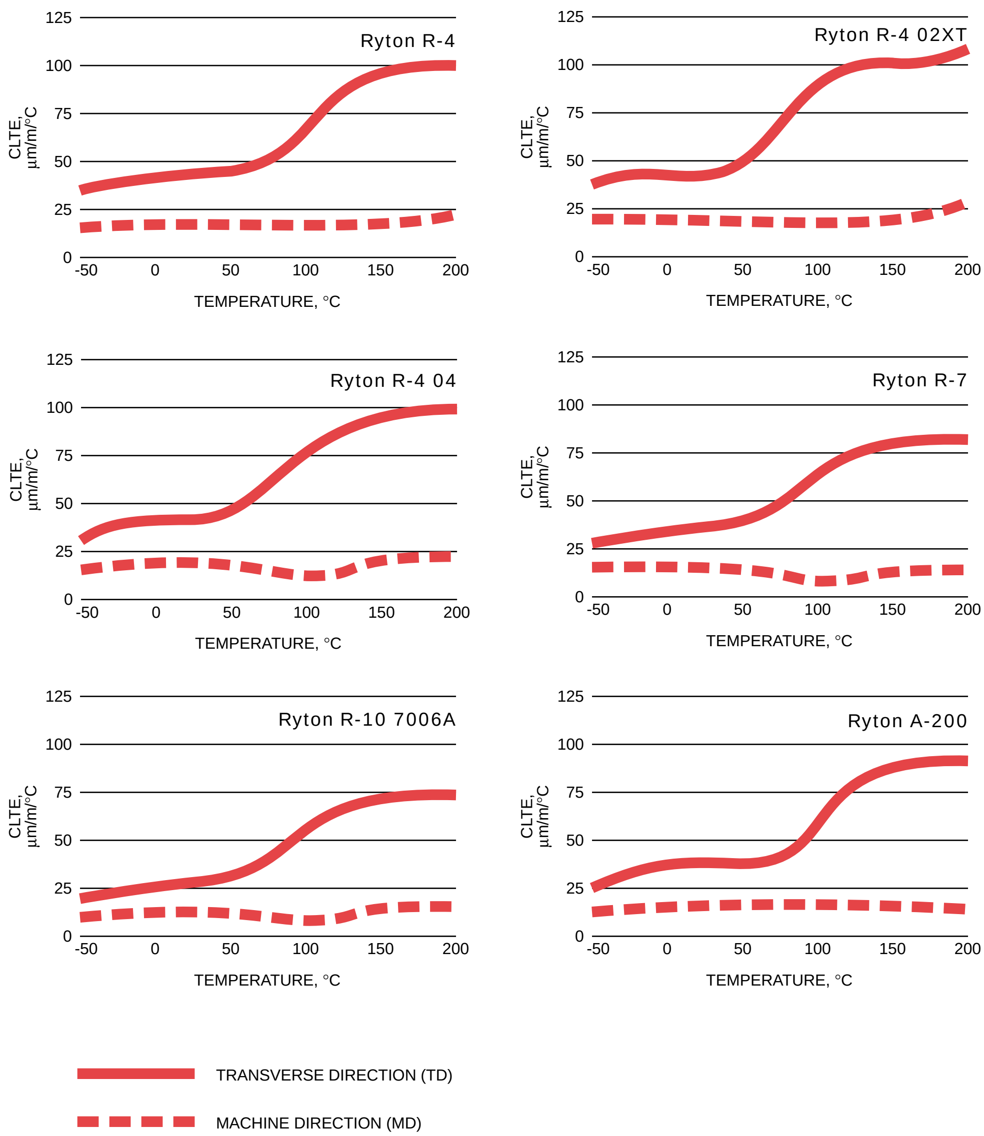


Coefficient of Linear Thermal Expansion

ASTM E831

The coefficient of linear thermal expansion is measured by the DuPont 943 thermal mechanical analyzer for -50°C to 250°C. This analyzer measures the variation in length of the Ryton PPS sample with the change in temperature and the results are measured in micrometer (µm) per meter of sample per degree Celsius.

Figure 2 – Effect of Temperature on Coefficient of Linear Thermal Expansion



Cryogenic Properties

The physical properties of Ryton PPS R-4 have been determined at cryogenic temperatures i.e., in liquid nitrogen (77°K) and liquid helium (4.2°K). As can be seen in *Table III*, mechanical performance is maintained at these extremely low temperatures. From additional studies, it appears that Ryton PPS R-4 also retains its excellent electrical properties at the cryogenic temperatures.

Table III – Cryogenic Properties of Ryton® PPS R-4

	Temperature		
Property	73.4°F	-320°F	-452°F
Flexural Strength, Ksi	28.0	38.5	40.5
Modulus of Elasticity, Msi	2.2	2.0	2.1
Hardness, Shore D	91	94	–
Thermal Contraction	73.4 to -320°F, (liquid nitrogen) = 0.296% 73.4 to -452°F, (liquid helium) = 0.340%		

Burning Characteristics

Although it can be ignited, Ryton PPS will neither sustain prolonged combustion nor support significant flame propagation when tested by any of the standard tests commonly used for plastics, e.g. ASTM D635, UL94. Unfortunately, no lab test can be expected to represent all the variables of an uncontrolled fire, such as a building or equipment fire, even if one fire scenario could be selected as “typical”. In various tests using heat, flame and electrical ignition sources, Ryton PPS will burn if the ignition source is hot enough, and will continue to burn until the source is removed. As it burns, it chars and may bubble somewhat, which can reduce heat transfer to the remaining material. In general, the compounds do not drip as they burn, but thin sections of the higher flow compounds can soften or melt enough to deform and may drip if the ignition source is hot enough.

The “flame-retardance” of Ryton PPS compounds is inherent to the stable chemistry of the resin itself. It does not rely on flame-retardant additives which can compromise the electrical and mechanical performance of compounds.

Although lab tests cannot predict burning behavior in a real life, they are presented here for comparison with other materials.

Ignition Temperature of Ryton® PPS R-4 (UL Test)

This test was performed by Underwriters Laboratories. It consists of placing some plastic chips or shavings into a glass flask that is submerged in a bath of molten alloy. The ignition chamber is purged and air added to assist ignition of the sample. If the test sample does not flame or glow, the flask is purged of residual gases, vapors and tested material. The temperature is raised and new sample added to the flask. This procedure is repeated until a minimum temperature is reached that induces the test material to glow or burn. That minimum combustion temperature is reported as the ignition temperature.

Ryton PPS R-4 1004°F

Flash Point

ASTM D1929

The flash point was determined by conventional procedures described in ISO R811 or ASTM D1929.

Ryton PPS R-4 Above 930°F

Flammability

ASTM E162

The radiant panel burn test measures the surface flammability of materials when exposed to a radiant heat source. A 6 x 18 inch specimen is mounted with its long dimension inclined 30° off the vertical. The specimen is parallel to, but 4 3/4 inch away from, a radiant panel heat source maintained at 1238 ± 72°F. A pilot burner ignites the top of the specimen, and the heat evolved by the specimen and its rate of burning are used to calculate a flame spread index, useful for comparing various materials.

Table IV – Flammability of Ryton® PPS Compounds

Grade	Average Thickness, inch	Flame Spread Index, inch	Visual Characteristics
R-4	0.134	2	Charring, slight melting, light smoke
R-10 7006A	0.134	2	Charring, light smoke

Oxygen Index

ASTM D2863

Oxygen index is a relative indication of flammability under a specific set of laboratory conditions. It is the minimum concentration of oxygen in a test atmosphere adequate to sustain continued burning of the test specimen for a specified period of time, or until a specified amount of material is consumed. The normal atmosphere contains 22% oxygen.

The oxygen index of several Ryton PPS compounds is presented in *Table V* with that of some other polymers for comparison purposes. These values for Ryton PPS indicate that it is much more resistant to prolonged burning than most other plastics.

Table V – Oxygen Index

Material	Oxygen Index, %
Ryton PPS R-10, R-7	53
Ryton PPS R-4	47
Ryton PPS R-4XT	53
Polyvinyl Chloride	47
Polyimide	44
Polyaryl-Sulfone	36
Aromatic Polyester	36
Polycrabonate (Flame-Retardant Grade)	32.5
Polysulfone (Flame-Retardant Grade)	32
Polyphenylene Oxide (Flame-Retardant Grade)	30
Nylon 6/6 (Flame-Retardant Grade)	28

Smoke Density
ASTM E662

The smoke test developed by the National Bureau of Standards employs a completely closed cabinet, measuring 3 x 3 x 2 feet deep. A 3 inch square specimen is supported in a frame such that a surface area 2 9/16 inch^2 is exposed to heat under either flaming or non-flaming (smoldering) conditions. The heat source is a circular foil radiometer adjusted to give a heat flux of 2.5 watts per square centimeter at the specimen surface.

The smoke density is measured photometrically in terms of light absorption. The photometer path is vertical to minimize measurement differences due to smoke stratification which could occur with a horizontal photometer path at some fixed height. The full 3 foot height of the chamber is used to provide an overall average for the entire chamber. Smoke measurements are expressed in terms of specific optical density, which represents the optical density measured over unit path length within a chamber of unit volume, produced from a specimen of unit surface area. Since this value is dimensionless, it provides the advantage of presenting smoke density independent of chamber volume, specimen size or photometer path length, provided a consistent dimensional system is used.

The time to reach a critical smoke density, also called obscuration time, is a measure of the time available before a “typical” occupant in a “typical” room would find his vision so obscured by smoke as to hinder escape. The value of specific optical density describing this critical level is 16, based on 16% light transmittance under certain specific conditions of room dimensions.

Table VI - Smoke Density of Ryton® PPS

		Max. Value of Specific Optical Density		Obscuration Time, min	
Material	Thickness, mils	Smoldering	Flaming	Smoldering	Flaming
R-4	60	23	171	15.5	2.7
	125	25	232	15.5	3.2
	170	19	78	16.6	5.8
R-7	125	18	68	16.7	6.0
R-10 7006A	170	16	44	18.6	8.6
Red Oak*	250	393	75	4.1	8.0

*Included for comparison purposes.

Products of Thermal Degradation

When polyphenylene sulfide is decomposed in the presence of air at approximately 1500°F, the major components are:

- Hydrogen
- Methane
- Carbon Monoxide
- Carbon Dioxide
- Carbonyl Sulfide

Minor Components identified are:

- Sulfur Dioxide
- Ethane or Ethylene

Ohio State University Flammability Evaluation

Phillips Petroleum Company successfully completed an evaluation for Ryton PPS R-4 and A-200 grades using the Ohio State University Flammability test. This test was conducted as a flammability evaluation of the submitted aircraft compartment interior materials in accordance with FAA 25.853 (a-1), Appendix F, Part IV, Test Method to Determine the Heat Release Rate from Cabin Materials Exposed to Radiant Heat. The two points recorded are the heat peak which is recorded at the maximum heat release (HRR) and the two minute heat release data point. The summary of results:

Grade	Peak HRR	Two-Minute Integrated HRR
R-4	78.7	-1.4
A-200	106.3	26.3

Identification of Off-Gases from Ryton® R-4

This information may be of use to those having a need to anneal Ryton PPS molded parts. The off-gases from Ryton PPS R-4 were collected and measured at 450°F for one hour and at 700°F for 10 minutes. The results are listed in *Table VII*.

Table VII – Off-Gases of Ryton® PPS R-4

	Constituents of R-4 Ryton PPS Off-Gas, ppm	
	1 hr @ 450°F	10 Min @ 700°F
Methane	2	
Carbon Monoxide	72	
Ethane/Ethylene	20	
Carbon Dioxide	974	0.69 mol. %
Propane	11	
Propylene	14	
Water Vapor	1004	1.04 mol. %
Carbonal Sulfide	<1	114
Isobutane	<1	
n-butane	<1	
Isopentane	<1	
3-Me-1-butene	<1	
Sulfur Dioxide	–	823
Carbon Disulfide	–	<0.1 mol. %

NASA Outgassing Test

ASTM E595-84

Ryton PPS compounds R-4, R-4 02XT, R-4 04, R-7 and A-200 have successfully passed the NASA outgassing test, carried out in accordance with ASTM procedures. There are two values recorded in this test. They are % TML, which is the percent of total material loss and % CVCM, which is the condensed volatile material.

The NASA outgassing requirement is a maximum of 1.0% TML and a maximum of 0.1% CVCM. All Ryton PPS compounds fall within the NASA specifications and the results are shown in *Table VIII*.

Table VIII – NASA Outgassing Test

Ryton PPS Grade	% TML	% CVCM
R-4	0.12	0.01
R-4 02XT	0.15	0.01
R-4 04	0.14	0.00
R-7	0.12	0.00
A-200	0.14	0.00