Appendix A: Surface Optical Property Data

Most surface property values contained in this Appendix are courtesy of NASA/GSFC.* Properties for materials marked with an asterisk*, however, are design values used by a particular program and are not from the NASA reference.

Unless otherwise noted, values are for beginning-of-life. For some surfaces, degraded values are shown for various periods of time on orbit. Because degradation rates are highly dependent on orbit altitude and the amount of contamination a surface experiences on a particular satellite, reported degraded values should be considered as rough estimates only. Chapter 4 contains extensive data on the degradation of optical solar reflectors and other materials.

Although all values shown are believed to be representative of those used for thermal design analyses in the industry, no guarantee of their validity is implied. In cases where a thermal design is sensitive to any of these parameters, surface optical property measurements and/or a solar-thermal balance test of the thermal design must be conducted to verify flight performance.

Material	α Solar	ε IR
Optical Solar Reflectors (OSR)		
Optical solar reflector (OSR), silvered fused silica (quartz)*	0.07	0.80
Optical solar reflector (OSR), diffuse*	0.10	0.80
Optical solar reflector, indium-tin-oxide (ITO) coated*	0.07	0.76
Optical solar reflector, silvered quartz, Helios program	0.07	0.79
Teflon, aluminized, 0.5 mil*	0.14	0.40
Teflon, aluminized, 1 mil*	0.14	0.48
Teflon, aluminized, 2 mil, sample 1*	0.14	0.60
Teflon, aluminized, 2 mil, sample 2*	0.08	0.66
Teflon, aluminized, tape, 2 mil*	0.17	0.76
Teflon, aluminized, sheet, 2 mil*	0.16	0.65
Teflon, aluminized, 5mil, sample 1*	0.22	0.81
Teflon, aluminized, 5 mil, sample 2*	0.13	0.81
Teflon, aluminized, 5 mil, sample 3*	0.17	0.77
Teflon, aluminized, 5 mil, sample 4*	0.14	0.75
Teflon, aluminized, 7.5 mil*	0.15	0.80
Teflon, aluminized, 10 mil, sample 1*	0.13	0.87

*J. H. Henninger, *Solar Absorptance and Thermal Emittance of Some Common Spacecraft Thermal Control Coatings*, NASA Reference Publication 1121 (1984).

Material	α Solar	ε IR
Teflon, aluminized, 10 mil, sample 2*	0.17	0.83
Teflon, aluminized, 10 mil, sample 3*	0.15	0.85
Teflon, silvered, 2 mil*	0.08	0.68
Teflon, silvered, 5 mil	0.08	0.81
Teflon, silvered, 10 mil*	0.09	0.88
Black Coating		
Black Z306 polyurethane paint, 3 mils thick, BOL*	0.95	0.87
Black Z306 polyurethane paint, 3 mils thick, 3 years GEO*	0.93	0.87
Black Z306 polyurethane paint, 3 mils thick, 5 years GEO*	0.92	0.87
Carbon black paint NS-7	0.96	0.88
Catalac black paint	0.96	0.88
Chemglaze Z306 black paint, BOL	0.96	0.91
Chemglaze Z306 black paint, EOL (time, orbit not specified)*	0.96	0.84
Delrin black plastic	0.96	0.87
Ebanol C black	0.97	0.73
Ebanol C black, 384 hours UV	0.97	0.75
GSFC black paint 313-1	0.96	0.86
GSFC black silicate MS-94	0.96	0.89
Hughson black paint H322	0.96	0.86
Hughson black paint L-300	0.95	0.84
Martin black paint N-150-1	0.94	0.94
Martin Black Velvet paint	0.91	0.94
Paladin black lacquer	0.95	0.75
Parsons black paint	0.98	0.91
Pyramil black on beryllium-copper	0.92	0.72
Rough black matte, black paint*	0.90	0.90
3M Black Velvet Paint, BOL	0.97	0.91
3M Black Velvet Paint, 2.5 years*	0.97	0.84
3M Black Velvet Paint, EOL*	0.97	0.84
Velvestat black plastic	0.96	0.85
Black anodize (see Anodize section)		

Material	α Solar	ε IR
Films and Tapes		
Aclar film, aluminized, 1 mil	0.12	0.45
Aclar film, aluminized, 2 mil	0.11	0.62
Aclar film, aluminized, 5 mil	0.11	0.73
Kapton, aluminized, aluminum side*	0.12	0.03
Kapton, aluminized, 0.08 mil	0.23	0.24
Kapton, aluminized, 0.15 mil	0.25	0.34
Kapton, aluminized, 0.25 mil	0.31	0.45
Kapton, aluminized, 0.50 mil	0.34	0.55
Kapton, aluminized, 0.50 mil, Dacron cloth reinforced*	0.35	0.53
Kapton, aluminized, 1 mil, sample 1	0.38	0.67
Kapton, aluminized, 1 mil, sample 2, BOL*	0.36	0.61
Kapton, aluminized, 1 mil, sample 2, 3 years GEO*	0.54	0.61
Kapton, aluminized, 1 mil, sample 2, 5 years GEO*	0.66	0.61
Kapton, aluminized, 1.5 mil	0.40	0.71
Kapton, aluminized, 2 mil, sample 1, BOL*	0.39	0.73
Kapton, aluminized, 2 mil, sample 1, 3 years (orbit not specified)*	0.55	0.73
Kapton, aluminized, 2 mil, sample 1, 5 years (orbit not specified)*	0.67	0.73
Kapton, aluminized, 2 mil, sample 2*	0.41	0.75
Kapton, aluminized, 2 mil, with indium-tin-oxide coating, BOL*	0.34	0.75
Kapton, aluminized, 2 mil, with indium-tin-oxide, 3 years (orbit not specified)*	0.47	0.75
Kapton, aluminized, 3 mil	0.45	0.82
Kapton, aluminized, 5 mil, sample 1, BOL*	0.49	0.83
Kapton, aluminized, 5 mil, sample 1, 2.5 years (orbit not specified)*	0.61	0.83
Kapton, aluminized, 5 mil, sample 1, EOL (time, orbit not specified)*	0. 70	0.83
Kapton, aluminized, 5 mil, sample 2	0.46	0.86
Kapton, aluminized, silicon oxide coated, 0.5 mil, BOL	0.12	0.18
Kapton, aluminized, silicon oxide coated, 0.5 mil, 4000 hours UV	0.28	0.24
Kapton, aluminized, chromium/silicon oxide coated (green), 1 mil	0.79	0.78

Material	α Solar	ε IR
Kapton, aluminized, aluminum-oxide coated, 1 mil	0.12	0.20
Kapton, aluminized, aluminum oxide coated, 1 mil, 1800 hours UV	0.12	0.20
Kapton, aluminized, silicon oxide coated, 1 mil	0.11	0.33
Kapton, aluminized, silicon oxide coated, 1 mil, 2400 hours UV	0.22	0.33
Kapton, silvered, aluminum oxide coated, 1 mil	0.08	0.19
Kapton, silvered, aluminum oxide coated, 1 mil, 2400 hours UV	0.08	0.21
Kapton, black (carbon loaded), 1 mil, BOL	0.92	0.88
Kapton, black (carbon loaded), 1 mil, 5 years GEO*	0.92	0.88
Kapton, black (carbon loaded), 1 mil, 10 years GEO*	0.89	0.88
Kimfoil polycarbonate film, aluminized, 0.8 mil	0.19	0.23
Kimfoil polycarbonate film, aluminized, 0.20 mil	0.20	0.30
Kimfoil polycarbonate film, aluminized, 0.24 mil	0.17	0.28
Mylar, aluminized, 0.15 mil (internal use only, disintegrates in sunlight)	–	0.28
Mylar, aluminized, 0.25 mil (internal use only, disintegrates in sunlight)	–	0.34
Mylar, aluminized, 3 mil (internal use only, disintegrates in sunlight)	–	0.76
Mylar, aluminized, 5 mil (internal use only, disintegrates in sunlight)	–	0.77
Silica cloth*	0.18	0.86
Skylab sail, initial	0.15	0.35
Skylab sail, 1900 hours UV	0.19	0.36
Skylab parasol fabric (orange), initial	0.51	0.86
Skylab parasol fabric (orange), 2400 hours UV	0.65	0.86
Tedlar, goldized, 0.5 mil	0.30	0.49
Tedlar, goldized, 1 mil	0.26	0.58
Tefzel, goldized, 0.5 mil	0.29	0.47
Tefzel, goldized, 1 mil	0.26	0.61
Teflon, goldized, 0.5 mil	0.24	0.43
Teflon, goldized, 1 mil	0.22	0.52
Teflon, goldized, 5 mil	0.22	0.81
Teflon, goldized, 10 mil	0.23	0.82

Material	α Solar	ε IR
Tape, 235-3M, black	0.95	0.90
Tape, aluminum*	0.10	0.04
Tape, 425-3M aluminum foil	0.20	0.03
Tape, aluminum, 2 mil, BOL*	0.15	0.04
Tape, 850-3M, aluminized Mylar	0.15	0.59
Tape, 7361 Mystic aluminized Kapton*	0.09	0.03
Tape, 7452 Mystic aluminum foil	0.14	0.03
Tape, 7800 Mystic aluminum foil	0.21	0.03
Tape, Y9360-3M, aluminized Mylar	0.19	0.03
White Coatings		
Skyspar, Andrew Brown Co.*	0.22	0.91
Barium sulphate with polyvinyl alcohol	0.06	0.88
Biphenyl (white solid)	0.23	0.86
Cat-a-lac white paint	0.24	0.90
Chemglaze A276 white paint*	0.23	0.88
Chemglaze A276, 15000 hrs UV in LEO, no atomic oxygen*	0.60	0.88
Chemglaze A276, 15000 hrs UV in LEO, atomic oxygen exposure*	0.35	0.88
DuPont Lucite acrylic lacquer	0.35	0.90
Dow Corning DC-007 white paint	0.19	0.88
Flamemaster Corp. STM K797 white paint, BOL*	0.22	0.85
Flamemaster Corp. STM K797 white paint, 4 years GEO*	0.60	0.85
NASA/GSFC NS43-C white paint	0.20	0.92
NASA/GSFC NS44-B white paint	0.34	0.91
NASA/GSFC NS74 white paint	0.17	0.92
NASA/GSFC NS-37 white paint	0.36	0.91
Hughson A-276 white paint	0.26	0.88
Hughson A-276 white paint, 1036 hours UV	0.44	0.88
Hughson V-200 white paint	0.26	0.89
Hughson Z-202 white paint	0.25	0.87
Hughson Z-202 white paint, 1000 hours UV	0.40	0.87
Hughson Z-255 white paint	0.25	0.89

Material	α Solar	ε IR
Magnesium oxide white paint	0.09	0.90
Magnesium oxide aluminum oxide paint	0.09	0.92
Opal glass	0.28	0.87
OSO-H 63W white paint	0.27	0.83
P764-1A white paint	0.23	0.92
Potassium fluorotitanate white paint	0.15	0.88
Sperex white paint	0.34	0.85
Dow Corning Thermatrol DC-92-007, BOL*	0.19	0.82
Dow Corning Thermatrol DC-92-007, 4 years GEO*	0.57	0.82
3M-401 white paint	0.25	0.91
Titanium oxide white paint with methyl silicone	0.20	0.90
Titanium oxide white paint with potassium silicate	0.17	0.92
Vita-var PV-100 white paint*	0.22	0.82
Z93 white paint*	0.19	0.89
S13 GLO white paint*	0.19	0.89
S13G white paint, BOL*	0.21	0.88
S13G white paint, 4 years GEO*	0.56	0.88
S-13G-LO white silicone paint, 10 mils thick, BOL*	0.22	0.88
S-13G-LO white silicone paint, 3 years GEO*	0.39	0.88
S-13G-LO white silicone paint, 10 mils thick, 5 years GEO*	0.47	0.88
Polyurethane white paint*	0.27	0.84
3M White Velvet 400 series white paint*	0.30	0.87
ZOT (IITRI YB-71) white paint, BOL*	0.20	0.91
ZOT (IITRI YB-71) white paint, 2.5 years (orbit not specified)*	0.45	0.91
ZOT (IITRI YB-71) white paint, EOL (time, orbit not specified)*	0.70	0.91
Zerlauts S-13G white paint, BOL	0.20	0.90
Zerlauts S-13G white paint, 2.5 years (orbit not specified)	0.52	0.85
Zerlauts S-13G white paint, EOL (time, orbit not specified)	0.70	0.85
Zerlauts Z-93 white paint	0.17	0.92
Z93 white paint, 10 years GEO*	0.55	0.92
ZOT (zinc orthotitanate) with potassium silicate	0.13	0.92

Material	α Solar	ε IR
Zinc oxide with sodium silicate	0.15	0.92
Zirconium oxide with 650 glass resin	0.23	0.88
Other Paints		
Brilliant aluminum paint	0.30	0.31
Chromacoat aluminum paint, BOL*	0.28	0.05
Chromacoat aluminum paint, 3 years (orbit not specified)*	0.33	0.05
Chromeric 586 silver paint	0.30	0.30
DuPont 4817 silver paint	0.43	0.49
Epoxy aluminum paint	0.77	0.81
Finch 643-1-1 aluminum paint	0.22	0.23
NASA/GSFC NS-43-G yellow paint	0.38	0.90
NASA/GSFC NS-53-B green paint	0.52	0.87
NASA/GSFC NS-43-E green paint	0.57	0.89
NASA/GSFC NS-43-C white paint	0.20	0.92
NASA/GSFC NS-55-F green paint	0.57	0.91
NASA/GSFC NS-79 green paint	0.57	0.91
Epon 828 leafing aluminum paint	0.37	0.36
80-U leafing aluminum paint	0.29	0.32
Naval Research Lab leafing aluminum paint	0.24	0.24
Naval Research Lab leafing aluminum paint	0.28	0.29
Silicone aluminum paint	0.29	0.30
Metals		
Aluminum, buffed*	0.16	0.03
Aluminum, heavily oxidized*	0.13	0.30
Aluminum, polished, BOL*	0.15	0.05
Aluminum, polished, EOL (time, orbit not specified)*	0.15	0.05
Aluminum, vapor deposited	0.08	0.02
Aluminum, vapor deposited, on fiberglass	0.15	0.07
Aluminum, vapor deposited, on stainless steel	0.08	0.02
Beryllium copper	0.31	0.03
Chromium, vapor deposited, on glass	0.56	0.17

Material	α Solar	ε IR
Chromium, vapor deposited, on 5 mil Kapton	0.57	0.24
Constantan-metal strip	0.37	0.09
Copper, buffed	0.30	0.03
Copper foil tape, plain	0.32	0.02
Copper foil tape, sanded	0.26	0.04
Copper foil tape, tarnished	0.55	0.04
Germanium, vapor deposited, on glass	0.52	0.09
Gold, vapor deposited, on glass	0.19	0.02
Gold, electroplated	0.23	0.03
Gold, polished, BOL*	0.30	0.05
Gold, polished, EOL (time, orbit not specified)*	0.30	0.05
Gold, sandblasted*	0.48	0.14
Inconel X foil, 1 mil	0.52	0.10
Iron oxide, vapor deposited, on glass	0.85	0.56
Molybdenum, vapor deposited, on glass	0.56	0.21
Nickel, vapor deposited, on glass	0.38	0.04
Nickel, electroless	0.39	0.07
Nickel, Kannigen alloy	0.45	0.08
Platinum foil	0.33	0.04
Rhodium, vapor deposited, on glass	0.18	0.03
Silver, vapor deposited, on glass, un-oxidized	0.04	0.02
Silver, polished, un-oxidized*	0.04	0.02
Silver, oxidized*	–	0.03
Silver, Denton vapor deposited, with protective overcoat*	0.06	0.03
Silver beryllium copper	0.19	0.03
Stainless steel, polished	0.42	0.11
Stainless steel, sandblasted	0.58	0.38
Stainless steel	0.47	0.14
Stainless steel, machine rolled	0.39	0.11
Stainless steel boom, polished	0.44	0.10
Stainless steel 304, 1 mil foil	0.40	0.05

Material	α Solar	ε IR
Tantalum foil	0.40	0.05
Titanium, vapor deposited on glass	0.52	0.12
Titanium*	0.40	0.55
Tungsten, polished	0.44	0.03
Tungsten, vapor deposited, on glass	0.60	0.27

Anodized Aluminum

The optical properties of anodized surfaces are highly dependent upon the anodizing process used. While the anodize properties shown below are representative, actual values may differ substantially from those shown here. Absorptance and emittance measurements of samples of the flight finish should therefore be made. A process for achieving controlled aluminum anodize properties is discussed in Chapter 4.

Material	α Solar	ε IR
Black anodize, sample 1	0.65	0.82
Black anodize, sample 2*	0.86	0.86
Black anodize, sample 3	0.76	0.88
Black anodize, sample 4	0.88	0.88
Blue anodize sample 1	0.67	0.87
Blue anodize sample 2	0.53	0.82
Brown anodize	0.73	0.86
Chromic anodize	0.44	0.56
Clear anodize sample 1	0.27	0.76
Clear anodize sample 2	0.35	0.84
Gold anodize	0.48	0.82
Green anodize	0.66	0.88
Plain anodize	0.26	0.04
Red anodize	0.57	0.88
Sulphuric anodize	0.42	0.87
Yellow anodize	0.47	0.87

Metal Conversion Coatings

The optical properties of conversion coatings are highly dependent upon the process used. While the properties shown below are representative, actual values may differ substantially from those shown here. Absorptance and emittance measurements of samples of the flight finish should therefore be made.

Material	α Solar	ε IR
Clad 7075 aluminum, BOL*	0.25	0.04

Material	α Solar	ε IR
Clad 7075 aluminum, 3 years GEO*	0.26	0.04
Clad 7075 aluminum, 5 years GEO*	0.27	0.04
Irridite aluminum	–	0.11
Alzac A-2	0.16	0.73
Alzac A-5	0.18	–
Black chrome	0.96	0.62
Black copper	0.98	0.63
Black irridite	0.62	0.17
Black nickel	0.91	0.66
Dow 7 on polished magnesium	–	0.49
Dow 7 on sanded magnesium	–	0.65
Dow 9 on magnesium	–	0.87
Dow 23 on magnesium	0.62	0.67
Ebanol C, black	0.97	0.77
TiNOX on copper*	0.95	0.05
Maxorb, nickel oxide or black chrome on nickel foil*	0.90	0.10
Blue anodize titanium foil*	0.70	0.13
Anodized titanium foil, 1 mil, BOL*	0.70	0.10
Anodized titanium foil c.p., 1 mil, 5 years GEO*	0.70	0.10
Composite Coatings		
Aluminum oxide, Al_20_3, 12 λ/4, on buffed aluminum	0.13	0.23
Aluminum oxide, Al_20_3, 12 λ/4, on buffed aluminum, 2560 hours UV	0.13	0.23
Aluminum oxide, Al_20_3, 12 λ/4, on fused silica glass	0.12	0.24
NASA/GSFC dark mirror coating, SiO-Cr-Al	0.86	0.04
NASA/GSFC composite, SiOx-Al_2-Ag	0.07	0.68
Inconel with Teflon overcoat, 1 mil	0.55	0.46
Silver beryllium copper with Kapton overcoat	0.31	0.57
Silver beryllium copper with Parylene C overcoat	0.22	0.34

Material	α Solar	ε IR
Silver beryllium copper with Teflon overcoat	0.12	0.38
Miscellaneous		
Vespel polyimide SP1*	0.89	0.90
Polyethylene, black *	0.93	0.92
Tedlar, black*	0.94	0.90
Tedlar, white*	0.39	0.87
Fiberglass epoxy (BOL and EOL are the same)*	0.72	0.89
Fiberglass polyimide, BOL*	0.75	0.89
Fiberglass polyimide, 2.5 years (orbit not specified)*	0.78	0.89
Fiberglass polymide, EOL (time, orbit not specified)*	0.80	0.89
Graphite epoxy (BOL and EOL are the same)*	0.93	0.85
Astroquartz fabric*	0.22	0.80
Beta cloth*	0.40	0.86
Grafoil BOL*	0.65	0.34
Grafoil EOL*	0.61	0.34

Appendix B: Material Thermal Properties

The room-temperature material property values contained in this appendix were obtained from a variety of sources. While the values shown are believed to be accurate, no guarantee of their validity is implied. In cases where a thermal design is sensitive to any of these parameters, material property tests and/or a design thermal balance test must be conducted to verify flight performance.

Solid Material Thermal Properties

Material	ρ (kg/cm³)	k (W/cm°C)	c_p (W-hr/kg°C)
Aluminum			
208	0.00277	1.212	
222	0.00277	1.333	
242	0.00277	1.506	
295	0.00277	1.437	
B295.0	0.00277	1.610	
308	0.00277	1.419	
319	0.00277	1.142	
355	0.00277	1.506	
C355.0	0.00277	1.419	
356	0.00277	1.593	
A356.	0.00277	1.593	
A380.	0.00277	1.004	
A413.0	0.00277	1.212	
443	0.00277	1.454	
B443.0	0.00277	1.471	
514	0.00277	1.385	
518	0.00277	0.969	
520	0.00277	0.883	
D712.0	0.00277	1.385	
1060-0	0.00277	2.354	
1060-H18	0.00277	2.302	
1100-0	0.00277	2.216	0.256
1100-H18	0.00277	2.216	
1350-0	0.00277	2.337	
2011-0	0.00277	1.437	0.267
2011-T3	0.00277	1.506	
2011-T8	0.00277	1.714	

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm^3)	k (W/cm°C)	c_p (W-hr/kg°C)
2014-0	0.00277	1.887	0.256
2014-T4	0.00277	1.333	
2014-T6	0.00277	1.558	
2017-0	0.00277	1.921	0.256
2024-0	0.00277	1.887	0.256
2024-T3	0.00277	1.212	
2024-T36	0.00277	1.212	
2024-T4	0.00277	1.212	
2024-T6	0.00277	1.212	
2025-T6	0.00277	1.558	
2036-0	0.00277	1.593	
2219-0	0.00277	1.731	
3003-0	0.00277	1.766	0.256
3003-H18	0.00277	1.766	
3004-0	0.00277	1.627	0.256
3004-H38	0.00277	1.627	
4032-0	0.00277	1.558	
4032-T6	0.00277	1.385	
5005-0	0.00277	2.060	0.267
5005-H38	0.00277	2.060	
5050-0	0.00277	1.921	0.256
5050-H38	0.00277	1.921	
5052-0	0.00277	1.385	0.256
5052-H38	0.00277	1.385	
5056-0	0.00277	1.160	0.256
5056-H38	0.00277	1.160	
5083-0	0.00277	1.177	0.267
5083-H38	0.00277	1.177	
5083-H113	0.00277	1.177	
5086-0	0.00277	1.264	0.267
5086-H34	0.00277	1.264	
5154-0	0.00277	1.264	0.267
5154-H38	0.00277	1.264	
5252-0	0.00277	1.385	
5254-0	0.00277	1.264	
5254-H38	0.00277	1.264	
5356-0	0.00277	1.177	

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm^3)	k (W/cm°C)	c_p (W-hr/kg°C)
5356-H38	0.00277	1.177	
5357-0	0.00277	1.679	
5357-H38	0.00277	1.679	
5454-0	0.00277	1.350	
5454-H38	0.00277	1.350	
5456-0	0.00277	1.177	0.267
5456-H38	0.00277	1.177	
5457-0	0.00277	1.766	
5652	0.00277	1.385	
5652-H38	0.00277	1.385	
6009-0	0.00277	1.662	
6053-0	0.00277	1.714	
6053-T4	0.00277	1.558	
6053-T5	0.00277	1.714	
6053-T6	0.00277	1.558	
6061-0	0.00277	1.800	
6061-T4	0.00277	1.558	0.267
6061-T6	0.00277	1.679	0.267
6062-0	0.00277	1.714	
6062-T4	0.00277	1.558	
6062-T6	0.00277	1.558	
6063-0	0.00277	2.181	
6063-T42	0.00277	1.921	
6063-T5	0.00277	2.008	
6063-T6	0.00277	2.008	
6063-T42	0.00277	1.921	
6063-T5	0.00277	2.008	
6063-T6	0.00277	2.008	
6262-T9	0.00277	1.714	
6463-0	0.00277	2.181	
6463-T42	0.00277	1.887	
6463-T5	0.00277	2.095	
6463-T6	0.00277	2.008	
7075-T6-T7	0.00277	1.212	0.267
7079-T6	0.00277	1.264	
7178-T6	0.00277	1.264	

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm^3)	k (W/cm°C)	c_p (W-hr/kg°C)
Beryllium			
Beryllium	0.00185	1.506	0.523
Be-38 Al	0.00208	2.129	
Be-96A	0.00183	1.419	0.500
Beryllium oxide	0.00230	1.385	0.291
Beryllia	0.00304	2.718	0.291
Copper			
C10200	0.00886	3.912	0.107
C10400,CX	0.00886	3.877	0.107
C11000	0.00886	3.912	0.107
C11300,CXX	0.00886	3.877	0.107
C12200	0.00886	3.393	0.107
C14500	0.00886	3.549	0.107
C14700	0.00886	3.739	0.107
C15000	0.00886	3.670	0.107
C15500	0.00886	3.462	0.107
C17200	0.00886		0.116
C17400	0.00886		
C18200	0.00886	3.237	0.107
C19400	0.00886	2.597	0.107
C21000	0.00886		0.105
C22000	0.00886	1.887	
C22600	0.00886	1.731	
C23000	0.00886	1.593	
C24000	0.00858	1.402	
C26000	0.00858	1.212	0.105
C26800, C27000	0.00858	1.160	0.105
C28000	0.00830	1.229	0.105
C31400	0.00886	1.800	0.105
C33000, CX	0.00858	0.012	0.105
C34000	0.00858	1.160	0.105
C34200, CX	0.00858	1.160	0.105
C36000	0.00858	1.160	0.105
C36500, CX	0.00830	1.229	0.105
C37000	0.00830	1.194	0.105
C37700	0.00858	1.229	0.105

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm³)	k (W/cm°C)	c_p (W-hr/kg°C)
C38500	0.00858	1.229	0.105
C40500, CX	0.00886		0.105
C44300, CX	0.00858	1.108	0.105
C46400, CX	0.00830	1.160	0.105
C48500	0.00858	1.160	0.105
C50500	0.00886	2.077	0.105
C51000	0.00886	0.692	0.105
C52100	0.00886	0.623	0.105
C52400	0.00886	0.502	0.105
C54400	0.00886	0.866	0.105
C61400	0.00803	0.675	0.105
C63800	0.00830	0.398	0.105
C64700	0.00886	1.766	0.105
C65100	0.00886	0.571	0.105
C65500	0.00858	0.364	0.105
C66700	0.00858	0.969	0.105
C67500	0.00830	1.056	0.105
C68700	0.00830	1.004	0.105
C68800	0.00830	0.398	0.105
C70600, CX	0.00886		0.105
C74500, CX	0.00858		0.105
C80100, CX	0.00886		0.105
C81400, CX	0.00886		0.105
C82000	0.00858	2.597	0.116
C82200	0.00886	1.835	0.116
C82400	0.00830	1.333	0.116
C82500	0.00830	1.298	0.116
C82600	0.00830	1.264	0.116
C82800	0.00830	1.229	0.116
C83600	0.00886	0.727	0.105
C84400, CX	0.00858		0.105
C86200, CX	0.00775	0.364	0.105
C87400	0.00830	0.277	0.105
C90300, Cx	0.00886	0.727	0.105
C92200, Cx	0.00858	0.727	0.105
C93200	0.00886	0.589	0.105
C93700	0.00886	0.467	0.105

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm^3)	k (W/cm°C)	c_p (W-hr/kg°C)
C94700	0.00886	0.537	0.105
C94800	0.00886	0.381	0.105
C95200, Cx	0.00747		0.105
C96200, Cx	0.00886		0.105
C97300, Cx	0.00886		0.105
C99300	0.00775	0.433	0.116
Delrin	0.00130	0.004	0.407
Fiberglass			
Fiberglass properties are anisotropic and vary depending on lay-up. Manufacturer's data or testing recommended to establish values.			
Gallium arsenide			
Gallium arsenide	0.00526	0.329	0.093
Germanium			
Germanium	0.00526	0.606	0.090
Glass			
Fused quartz	0.00221	0.015	0.198
Hydrazine			
Liquid	0.00100	0.005	0.861
Solid	0.00116	0.017	0.558
Invar			
Invar	0.00803	0.133	0.140
Kapton			
Standard	0.00141	0.002	0.279
(Black)	0.00130	0.002	0.302
Kovar		0.164	
Magnesium			
AZ31B-F, A	0.00180	0.762	0.291
AZ61A-F	0.00180	0.589	0.291
AZ80A-T5	0.00180	0.502	0.291
ZK60A-T5	0.00180	1.194	0.291
HK31A-H24	0.00180	1.142	0.291
HM21A-T8	0.00180	1.367	0.291
HM31A-T5	0.00180	1.039	0.291
AZ63A	0.00180		0.291
AZ81A	0.00180	0.502	0.291
AZ91A, a	0.00180	0.537	0.291

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm³)	k (W/cm°C)	c_p (W-hr/kg°C)
AZ91C	0.00180		0.291
AZ92A	0.00180		0.291
AM100A	0.00180		0.291
EZ33A-T5	0.00180	1.004	0.291
HK31A-T6	0.00180	0.900	0.291
Molybdenum			
Molybdenum	0.01024	1.471	0.076
TZM	0.01024	1.471	0.076
Mycalex	0.00233		0.140
Nickel			
INCO Alloy	0.00803	0.123	0.128
Incol	0.00803	0.114	0.128
Inconel 825	0.00830	0.111	0.128
Inconel 600	0.00830	0.149	0.128
Inconel 601	0.00803	0.113	0.128
Inconel 625	0.00858	0.099	0.116
Berylm Nic	0.00803		0.140
Monel 400	0.00803	0.218	0.116
Monel 404	0.00886	0.211	0.116
Monel R-405	0.00886	0.218	0.116
Monel K-500	0.00858	0.175	0.116
Monel 502	0.00858	0.175	0.116
80 Ni	0.00830	0.004	0.128
75 Ni	0.00830	0.004	0.128
70 Ni	0.00830	0.004	0.128
60 Ni	0.00830	0.004	0.128
Hast	0.00913	0.134	0.105
Haste	0.00886	0.113	0.105
Alloy C-276	0.00886	0.130	0.116
Alloy G	0.00830	1.541	0.105
IN102	0.00858	0.113	
Inconel 600	0.00803	0.113	0.128
Inconel 617	0.00830	0.135	
Inconel 625	0.00803	0.118	0.128
Inconel 690	0.00830	0.114	
Inconel 700	0.00803	0.125	0.128
Inconel 706	0.00803	0.126	

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm³)	k (W/cm°C)	c_p (W-hr/kg°C)
Inconel 718	0.00830	0.113	
Inconel 722	0.00830	0.147	
Inc X-750	0.00830	0.119	
901	0.00830	0.133	
B-1900	0.00830	0.118	
D-979	0.00830	0.126	
MAR-M	0.00858	0.211	0.233
MAR-M-246	0.00858	0.251	
MAR-M	0.00803	0.270	
TD NI	0.00886	0.467	0.128
TD Ni Cr	0.00858	0.381	
Udimet 500	0.00803	0.244	0.116
Waspaloy	0.00830	0.168	
Nicrotung	0.00830	0.152	
Rene-41, R	0.00830	0.161	
GMR-235-D	0.00803	0.142	
Ha S	0.00886	0.142	
Has X	0.00830	0.158	0.128
Udimet HX	0.00830	0.158	0.128
Unite HX	0.00830	0.158	0.128
INCO HX	0.00830	0.158	0.128
RTV			
11	0.00111	0.003	
21, 41	0.00119	0.003	
31, 60	0.00133	0.003	
511	0.00108	0.003	
560, 577	0.00127	0.003	
615	0.00091	0.002	
616	0.00111	0.003	
630	0.00116	0.003	
632	0.00113	0.003	
634	0.00108	0.003	
619	0.00089	0.002	
627	0.00127	0.003	
655, 670	0.00097	0.002	
8111, 8112	0.00108	0.003	
8262	0.00136	0.003	

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm³)	k (W/cm°C)	c_p (W-hr/kg°C)
Silicon	0.00233	1.489	0.198
Stainless steel			
201, 202	0.00803	0.163	0.140
203EX	0.00775	0.163	0.140
211	0.00775		
216	0.00803		
301	0.00803	0.163	0.140
302	0.00803	0.163	0.140
302B	0.00803	0.159	0.140
302HQ	0.00803	0.113	0.140
303, 303 Se	0.00803	0.163	0.140
303 PLUS-X	0.00803	0.163	0.140
304	0.00803	0.163	0.140
304L, 304LN	0.00803	0.163	0.140
305	0.00803	0.163	0.140
308	0.00803	0.152	0.140
309, 309S	0.00803	0.156	0.140
310, 310S	0.00803	0.142	0.140
316	0.00803	0.163	0.140
316L	0.00803	0.163	0.140
317	0.00803	0.163	0.140
321	0.00803	0.161	0.140
347-348	0.00803	0.161	0.140
384-385	0.00803	0.164	0.140
403	0.00775	0.249	0.128
405	0.00775	0.270	0.128
410, 410CB	0.00775	0.249	0.128
414	0.00775	0.249	0.128
416, 416SE	0.00775	0.249	0.128
420	0.00775	0.249	0.128
420F	0.00775	0.249	0.128
429	0.00775	0.256	0.128
430	0.00775	0.261	0.128
430F-430FSE	0.00775	0.261	0.128
431	0.00775	0.203	0.128
434	0.00775	0.263	0.128
436	0.00775	0.239	0.128

Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm^3)	k (W/cm°C)	c_p (W-hr/kg°C)
440A, B, C	0.00775	0.242	0.128
446	0.00747	0.209	0.140
501	0.00775	0.367	0.128
502	0.00775	0.367	0.128
Stainless W	0.00775	0.209	
17-4 PH	0.00775	0.180	
CB-7 Cu	0.00775	0.171	
17-7 PH	0.00775	0.168	
PH 15-7 MO	0.00775	0.161	
17-14 Cu Mo	0.00775	0.151	
AM-350	0.00775	0.154	
AM-355	0.00775	0.159	
JS700	0.00803	0.147	0.140
Uniloy 326	0.00775	0.196	0.116
Nitronic 40	0.00775	0.138	
Nitronic 50	0.00775	0.156	
CA-6NM	0.00775	0.251	0.128
CA-15	0.00775	0.251	0.128
CB-30	0.00747	0.222	0.128
CC-50	0.00747	0.218	0.140
CF-3M	0.00775	0.163	0.140
CD-4M Cu	0.00775	0.152	0.128
CE-30	0.00775	0.147	0.163
CF-3	0.00775	0.159	0.140
CF-8	0.00775	0.159	0.140
CF-20	0.00775	0.159	0.140
CF-8M, CF-12M	0.00775	0.163	0.140
CF-8C	0.00775	0.161	0.140
CF-16F	0.00775	0.163	0.140
CG-8M	0.00775	0.163	0.140
CH-20	0.00775	0.142	0.140
CK-20	0.00775	0.137	0.140
CN-7M	0.00775	0.209	0.128
HA	0.00775	0.260	0.128
HC	0.00775	0.218	0.140
HD	0.00775	0.218	0.140
HE	0.00775	0.147	0.163

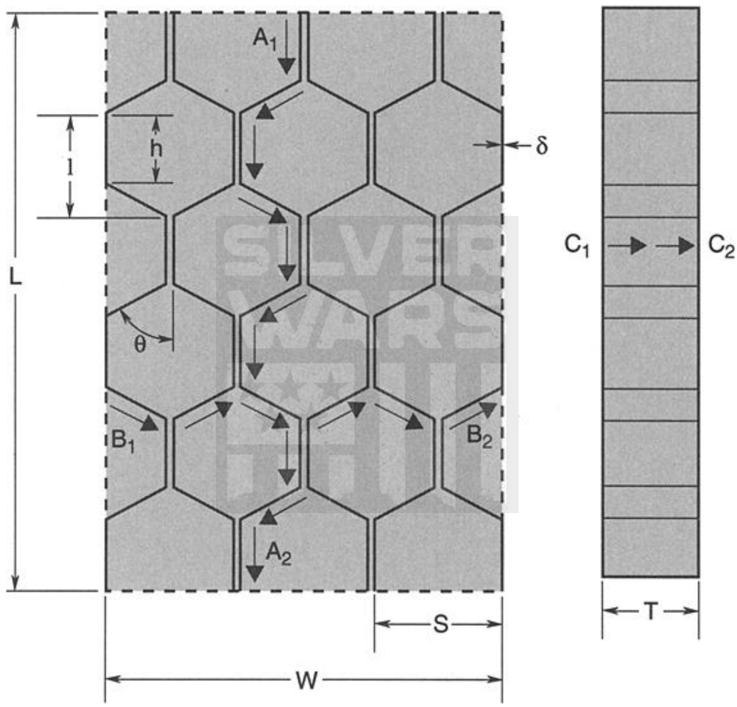
Solid Material Thermal Properties *(Continued)*

Material	ρ (kg/cm^3)	k (W/cm°C)	c_p (W-hr/kg°C)
HF	0.00775	0.144	0.140
HH	0.00775	0.142	0.140
HI	0.00775	0.142	0.140
HK	0.00775	0.137	0.140
HL	0.00775	0.142	0.140
HN	0.00775	0.130	0.128
HP	0.00775	0.130	0.128
HT	0.00803	0.121	0.128
HU	0.00803	0.121	0.128
HW	0.00803	0.125	0.128
HX	0.00803	0.125	0.128
Tantalum	0.01661	0.545	0.042
Teflon			
FEP	0.00221	0.002	0.279
TFE	0.00221	0.002	0.267
Titanium			
Titanium	0.00443		0.145
Ti-0.15-0.2 Pd	0.00443	0.078	0.145
Ti-5Al-2.5 Sn	0.00443	0.078	0.145
Ti-5AL-6Sn-2Zr-1Mo	0.00443	0.066	0.145
Ti-8AL-1Mo-1V	0.00443	0.073	0.145
Ti-6Al-4V cast	0.00443	0.073	0.159
Ti-8Mn	0.00471	0.109	0.137
Ti-6Al-2Sn-4Zr-6Mo	0.00471	0.071	
Ti-6Al-6V-2Sn	0.00443	0.073	0.180
Ti-6Al-2Sn-4Zr-2Mo	0.00443	0.061	0.116
Ti-3Al-13V-11Cr		0.069	0.140
Tungsten	0.01938	1.679	0.040

Honeycomb Panel Thermal Properties

Honeycomb composites of various types are commonly used on spacecraft as equipment shelves, solar-array substrates, etc. The following equations for calculating the effective conductivity through honeycomb core material in different directions were developed by Lee Hennis of Boeing Satellite Systems.

Because of its construction, honeycomb has directionally dependent conductivities. These are presented for each of the three directions for a general hexagonal honeycomb structure, as well as the typical regular hexagonal structure. The final "k" and "C" equations given at the end of each section are expressed in terms of variables that can be obtained from the face of an engineering drawing. It should be noted that this section deals exclusively with the core material and does not in any way include the facesheets that will be bonded to the core. Also, radiation exchange between walls of hexagonal structure has been excluded from this discussion. (Note: radiation-heat transfer is small compared to conduction for aluminum honeycomb panels. –Editor)



Nomenclature

- L = Overall honeycomb length (in the ribbon direction)
- W = Overall honeycomb width (perpendicular to ribbon direction)
- T = Thickness of honeycomb
- S = Cell size, face to face
- δ = Ribbon thickness
- h = Length of cell wall
- θ = Cell angle

Conduction in the "L" direction

For one ribbon:

$C_{A_1 - A_2} = KA/x$

where k = conductivity of the ribbon material

A = cross-sectional area of the ribbon

x = total length of the ribbon

$A = \delta T$

$x = \sigma L$

where σ = an extension factor

$\sigma = 2h/l$

$l = h + h\cos\theta$

therefore s = 2/(+ cos θ)

Substituting:

$$C_{A_1 - A_2} = k\delta T/\sigma L$$

Now for n ribbons: (It is assumed that the net heat interchange between ribbons is negligible for this directional calculation.)

n = # of ribbons

$n = 2W/S$ (W/S = # of cells in the W direction)

$CL = kA/x$

where k = conductivity of the honeycomb material

$A = \delta T(2W/S)$

$x = \sigma L$

Substituting:

$$CL = (2k\delta/\sigma S)(WT/L)$$

or $\bar{k}_L$ = equivalent honeycomb conductivity in "L" direction

$$\bar{k}_L = 2k\delta/\sigma S$$

For the normal hexagonal honeycomb structure:

$\theta = 60^\circ$

$\sigma = 2/(l + \cos 60^\circ)$

$\sigma = 2/1.5 = 4/3$

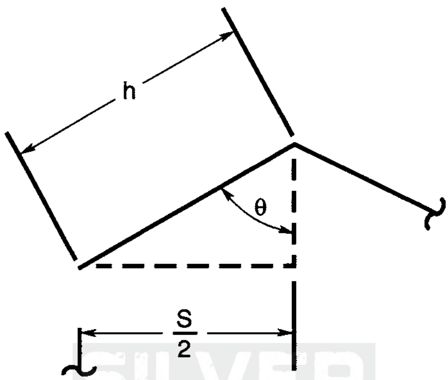
Substituting:

$$\bar{k}_L = 3k\delta/2S$$

$$\boxed{CL = (3k\delta/2S)(WT/L)}$$

Conduction in the "W" direction

For one path $B_1 - B_2$: (It is assumed that the net heat interchange between paths is negligible for this directional calculation. It can be shown that the contact resistance at the ribbon interfaces along the path is also negligible compared to the material resistance.)



$C_{B_1-B_2} = kA/x$

where k = path material conductivity

A = cross-sectional area of the path

x = total path length

$A = \delta T$

$x = nh\ (n = 2W/S)$

$x = 2Wh/S$

$\sin\theta = S/2h$

$h = s/2\sin\theta$

therefore $x = W/\sin\theta$

Substituting:

$$C_{B_1-B_2} = k\delta T\sin\theta/W$$

Now for m paths:

m = # of paths

$m = L/l = L/(h + h\cos\theta) = \sigma L/2h = \sigma L\sin\theta/S$

$C_W = kA/x$

where k = conductivity of the honeycomb material

$A = m\,\delta T = \delta T(\sigma L\sin\theta/S)$

$x = W/\sin\theta$

Substituting:

$$C_W = (k\,\delta\sigma\sin^2\theta/S)(LT/W)$$

or $\bar{k}_W$ = equivalent honeycomb conductivity in "W" direction

$$\bar{k}_W = k\,\delta\sigma \sin^2\theta / S$$

For the normal hexagonal honeycomb structure:

$\theta = 60^\circ$

$\sin^2\theta = 3/4$

$\sigma = 4/3$

Substituting:

$\bar{k}_W = k\,\delta / S$

$$\boxed{C_W = (k\,\delta/S)(LT/W)}$$

Conduction in the "T" direction

For one ribbon:

$C_{C_1 - C_2} = kA/x$

where k = conductivity of the ribbon material

A = cross-sectional area of the path

x = total path length

A = $\sigma L \delta$

x = T

Substituting:

$C_{C_1 - C_2} = k\sigma\delta\, L/T$

Now for n ribbons: (It is assumed that the net heat interchange between ribbons is negligible for this directional calculation.)

$C_T = kA/x$

where k = conductivity of the honeycomb material

A = $n\,\sigma\delta L$

n = $2W/S$

A = $2\sigma\delta LW/S$

x = T

Substituting:

$C_T = 2k\sigma\delta LW/ST$

or $\bar{k}_T$ = equivalent honeycomb conductivity in "T" direction

$\bar{k}_T = 2k\sigma\delta/S$

For the normal hexagonal honeycomb structure:

$\theta = 60^\circ$

$\sigma = 4/3$

Substituting:

$$\bar{k}_T = 8k\sigma\delta/3S$$

$$\boxed{C_T = (8k\sigma\delta/3S)\,(LW/T)}$$

Appendix C: Thermally Conductive Filler Materials and Suppliers

The following table contains detailed data for a wide variety of thermal interface enhancement materials. Not all of these have been qualified for spacecraft use. Verification of suitability for use in a space environment may therefore be required. Note: Content and volume of "Table of Typical Properties" depends on presented manufacturer information. In most cases the following data are included: density, color, thickness range, thermal impedance, thermal conductivity, operation temperature, dielectric strength, volume resistivity, adhesive characteristics, storage life, cleanability.

		Basic Characteristics					
Material	Advantages Application	Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	Manufacturer
Toptherm Red 86/82	High thermal conductivity, electrical isolation, best surface contact. Placed between hot devices (semiconductors) and heat sinks. Power, radio, TV, computer industries.	0.225	6.5	–40 to +250	Table of typical properties Breakdown voltage: >1 k V	Flexible foil based on elastomer with ceramic fillers	Alfatec Kerafol gmbh
Kera-therm Grafite 90/10	High thermal conductivity, electrically conductive. Mostly used in the CPU applications. 90/10-S version is combined with phase change material	0.2	55 in X and Y direction, 5.5 in Z direction	–40 to +500	Table of typical properties	100% pure graphite in blank version or laminated with wax, adhesive, or filled adhesive	Meckenloher Str.11 Rednitzhembach, Bayern 91126 Germany
Kera-therm Blue Soft-therm 86/200 G4	No outgassing, very soft and highly compressible. For RIMM—800 Mhz Modules between the small sensitive silicon-chips and the heat sink on top of them, http://www.rimm.com/; for flip chips	0.5 to 1.0	1.5	–40 to +120	Table of typical properties. Diagrams: deflection vs. pressure, thermal resistance vs. pressure. Dielectric breakdown of 15 kV/mm	Silicone free, ceramic filled; available in high mechanical strength or high thermal conductivity versions	Tel. +49 9122.9796.0 Fax +49 9122.9796.50 Email info@alfatec.de Web www.alfatec.de

Material	Advantages Application	Basic Characteristics				Structure	Manufacturer
		Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data		
Kera-therm Softtherm 86/260	Conformable and compressible polymer. PSA applications where enhanced stickiness required. Most suitable for heat-plate application.	0.5 to 5.0	1.5	–60 to +200	Table of typical properties. Diagram of compressibility. Dielectric breakdown of 10 kV/mm	Gap filler based on silicone polymer filled with ceramic powder	
Kera-therm Blue U23 (Polyure-thane)	Flexible foil, high electrical isolation, high mechanical strength. Power electronics, power supply	0.225	1.2	–40 to +90	Table of typical properties. Dielectric breakdown of 40kV/mm	Silicone free foil (based on polyure-thane)	
Kera-therm Copper 86/70	High flexibility. For EMC shielding, PC Boards.	0.25	1.7	–60 to +250	Table of typical properties. Dielectric breakdown of 1kV/mm	Copper lining on one side of foil	
Kera-therm Pink 86/50	High thermal conductivity, good electrical isolation. Especially suitable for power modules in which large quantities of heat needs to be conducted. Aerospace applications.	0.225	2.9	–60 to +250	Table of typical properties. Dielectric breakdown of 7 kV/mm	Standard foil filled with boron nitride. Available with PSA, fiberglass reinforced or combination	
Kera-therm Green 86/37	Especially suitable for use in industries requiring high electrical isolation. Automotive electronics, mechanical engineering, aviation.	0.225	1.8	–60 to +250	Table of typical properties. Dielectric breakdown of 26kV/mm	Available in basic version, or with one side PSA, fiberglass reinforced and com-bination	

Material	Advantages Application	Basic Characteristics: Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	Manufacturer
T-pli 200 Series™	Combination of very high thermal conductivity with soft compliant surface. Used as a mounting material between a solid state heat generating component and its heat sink. Micro heat pipe thermal solutions.	0.125 to 5	6	–40 to +200	Table of typical properties. Diagrams: thickness vs. thermal resistance, pressure vs. deflection. Dielectric strength: 3.2 to 6 kV	Boron nitride filled silicone elastomer	Thermagon, Inc. 4707 Detroit Ave., Cleveland, OH 44102 USA
T-gon 200 Series™	Thermally conductive insulator, good chemical resistance mechanical and physical performances. Used in interfaces where pressure is applied: diodes, resistors, micro-processors.	0.2 to 0.5	5	–60 to +200	Table of typical properties. High thermal stability to 200°C. Dielectric strength: >6 kV	Boron nitride filled silicone elastomer, fiberglass reinforced	Tel. 216.939.2300 Fax 216.939.2310
T-gon 800 Series™	Thermally and electrically conductive, conformable, good shock resistance. For cost-sensitive applications. Between heat sinks and semiconductor packages, most power devices	0.125 to 0.5	140 in X and Y direction, 5 in Z direction	–20 to +200	Table of typical properties	Grain-oriented, plate-like structure from graphitic composite—98% graphite without binders or additives	Email info@thermagon.com Web www.thermagon.com
T-flex 600 Series™	Ultimate blend of softness, compressibility and thermal conductivity. Used to blanket highly uneven surfaces; notebooks and automotive application, heat pipe thermal solutions	0.5 to 5	3	–45 to +200	Table of typical properties. Dielectric strength: >6 kV	Ultra soft polymer-based gap filler – boron nitride filled silicone elastomer	

Material	Advantages Application	Basic Characteristics				Structure	Manufacturer
		Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data		
T-putty 502 Series™	Ultra soft thermally conductive putty. Used in applications where large tolerance differences can create the need for compression of the interface material beyond 50% of its original thickness, and to prevent cracking when interfacing ceramic modules to metal parts	0.5 to 5	3	–45 to +200	Table of typical properties. Dielectric strength: >6 kV	Boron nitride filled silicone elastomer, fiberglass reinforced	
T-form 400 series™	Combination of high thermal conductivity with elasticity and conformability of a soft gap filler, as well unprecedented strength. Used in semiconductor equipment, notebook manufacture. Micro heat pipe thermal solutions.	0.25 to 5	6	–45 to +200	Table of typical properties. Pressure—0.69 10^5 N/m^2. Diagram: thickness vs. thermal resistance. Elongation—up to 120%. Dielectric strength: >6 kV	Boron nitride filled, silicone elastomer	
Sil-less T-grease	Reduced contamination	–	0.8 to 2.5	–40 to +200	Table of typical properties	Silicone free joint compound (paste)	
Kool-pads K230	Thermally conductive, electric insulator. Used for high reliability equipment. Military, aerospace industries	0.23	1.1	–60 to +180	Table of typical properties, breakdown voltage: 4.5 kV, mounting pressures: 20.58 to 41.16 10^5 N/m^2	Low silicone content based interface material includes highly conductive fillers	Warth International LTD Birches Industrial Estate, East Grinstead, West Sussex RH19 1XH United Kingdom

Material	Advantages Application	Basic Characteristics					Manufacturer
		Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	
Kool-pads CM20	No outgassing, excellent heat transfer and electrical conductivity. Interfacing heat sinks, power modules.	0.2	3.9	–200 to +500	Table of typical properties. Diagram: torque per bolt vs. thermal resistance, recommended compression: 34.3 10^5 N/m^2	Dry carbon structure pads consisting of 98% graphite	Tel. +44 (0) 1342.315044 Fax +44(0) 1342.312969
Kool-pads PK17, PK23	Low cost, strong flexible and clean insulator, which will not crack, age, or permit contamination. Aerospace, telecommunication applications.	0.229	0.8 to 1.1	–20 to +150	Table of typical properties, breakdown voltage: 4.5 to 5.5 kV	Free of silicone polyester compound coated onto a layer of woven glass fibre	Email solutions@warth.co.uk Web www.warth.co.uk
KoolForm (KF)	Highly conformable thermally conductive air gap filler. Fills irregular gaps between hot electronic components and their adjoining heatsinks or mounting chassis. Electronics.	0.25 to 5	1.5 to 2.2	–60 to +200	Table of typical properties, breakdown voltage: >5 kV	Low modulus silicone polymer loaded with thermally conductive particles	
Kool-pads K381	High performance thermally conductive, electric isolator.	0.381	3.4	–60 to +180	Table of typical properties, breakdown voltage: 4 kV	Silicone elastomer specially loaded with boron nitride	

Material	Advantages Application	Basic Characteristics					Manufacturer
		Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	
Kool-pads HeatPath GTQ 1500	Combining softness and compressibility with good thermal performance and excellent surface wetting. Used in higher specification products.	0.25 to 1	1.1	–40 to +150	Table of typical properties. Dielectric breakdown voltage: 2 to 6 kV	Alumina-filled silicone gel incorporates a fiberglass carrier	
C695	Flexible, thermally and electrically conductive. Used in applications with multiple components on large heat sink	1.3	4.0	–30 to +150	Table of typical properties. Diagram: contact pressure vs. thermal resistance. Contact pressure: <1.38 10^5 N/m^2	0.13 mm graphite film coated on one side with 0.025mm acrylic pressure sensitive adhesive (PSA)	Saint-Gobain Performance Plastics 14 McCaffrey St. Hoosick Falls, NY 12090-0320 USA
C675	Thermally conductive. Used in attaching microprocessors or isolated components to heat sink.	1.5	1.1	–30 to +150	Table of typical properties. Diagram: contact pressure vs. thermal resistance. Contact pressure: <1.38 10^5 N/m^2	Material is constructed of 0.05 mm aluminum foil coated on both sides with 0.05mm acrylic PSA	Tel. 800.962.2666 518.686.7301 Fax 518.686.4840
Furon 400 Series	Soft, thermally conductive, good dielectric. Heat transfer gasket between power devices, heat generating devices and their mountings.	0.01 to 0.5	0.45 to 1	–27 to +204	Table of typical properties. Dielectric strength: 3.5 to 10 kV	Silicone coated fiberglass fabrics	Email Joanne.Brahan@saint-gobain.com Web www.furon.com

		Basic Characteristics					
Material	Advantages Application	Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	Manufacturer
HTSP	High thermal conductance. Encapsulating, cable jointing, sealing and protection: manufacturing industries		2.9	–50 to +200	Table of typical properties	Silicone compound	Electrolube Wentworth House, Blakes Road Wargrave Berkshire PG108AW UK Tel.+44(0)118.940.4031/3014 Fax +44 (0)118.940.3084
Cool-pad CPR 7156	Conformable thermal pad can be pre-applied onto heat sinks. Used inP C microprocessors, power supplies, between power devices and heat sinks		4	–55 to +150	Table of typical properties. Dielectric strength: > 20 kV/mm	Polymer interface pad	A.I.Technology, Inc. 70 Washington Rd. Princeton Junction, NJ 08550 USA
ME 8456-XT	Proven success for large area bonding. Electrically conductive. Electronics.		4 to 8	–55 to +150	Table of typical properties, outgassing data: TML = 0.25%, VCM = 0.05%	Flexible Ag-filled epoxy	Tel. 609.799.9388 Fax 609.799.9308 Email ait@aitechnology.com Web www.aitechnology.com
Polarchip CP7003	Soft, conformable, highly compressible material. Used for filling air gaps between heat generating devices on printed circuit boards and the heat sinks. Electronics.	0.5 to 2.0		–50 to +150	Table of typical properties. Diagrams: applied pressure vs. compression, initial clamping pressure vs. thermal impedance	Fluoropolymer composite consisting of an expanded polytetrafluoroethylene matrix filled with boron nitride particles	W. L. Gore & Associates, Inc. 2020 Prairie Lane Eau Claire, WI 54703 USA Tel. 800.445.4673

		Basic Characteristics					
Material	Advantages Application	Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	Manufacturer
Polarchip CP8000	Used for filling the air gaps between heat generating devices on printed circuit boards and the heat sinks, heat spreaders, and metal chassis that are used to dissipate the heat. Electronics.	0.5 to 2.0		–50 to +150	Table of typical properties. Diagrams: applied pressure vs. compression, initial clamping pressure vs. thermal impedance.	Fluoropolymer composite consisting of an expanded polytetrafluoroethylene matrix filled with boron nitride particles	Fax 800.757.4673 Email bmahre@wgore.com Web www.gore.com/electronics
Sure-form	Highly conformable, soft, naturally tacky, for high compression loads. Used where surfaces textures vary and the space between surfaces is uneven. Electronics, optics.	2 and above	1.7	–40 to +150	Table of typical properties. Dielectric strength: 12.5 kV/mm	Gap filler formulated with non-silicone, dry-to-touch thermal grease	AOS Thermal Compounds 22 Meridian Road Suite 6 Eatontown, NJ 07724 USA
AOS Non-silicone HTC-60 (52031)	Superior thermal conductivity. Interfacing between a heat generating device and heat sink metal chassis		2.5	–40 to +200	Table of typical properties. Dielectric strength: 13.8 kV/mm	Non-silicone paste	Tel. 732.389.5514 Fax 732.389.6380
AOS Electrically Conductive Grease (57000)	Premium electrical and thermal conductivity, thermally stable and nonflammable. Low power electronic and high power electrical applications.		7.2	–40 to +200	Table of typical properties	Chemically inert heat sink compound—paste	Email sales@aosco.com Web www.aosco.com

Material	Advantages Application	Basic Characteristics					Manufacturer
		Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	
Poly-pads	Thermally conductive insulators for silicone-sensitive application. Aerospace applications	0.15; 0.23	0.9 to1.3	–20 to +150	Table of typical properties. Breakdown voltage: 2.5 to 6 kV	Ceramic filled polyester resins coating either side of a fiberglass carrier or a Kapton carrier	The Bergquist Company 18930 West 78th Street Chanhassen, MN 55317 USA
Sil-pad 1000	Thermally conductive electrical insulator. Used to electrically isolate power sources from heat sinks	0.23	1.2	–60 to +180	Table of typical properties, outgassing data: TML = 0.22%, CVCM = 0.08%. Breakdown voltage: 4.5 kV	Composite of silicone rubber and fiberglass special filled	Tel. 952.835.2322 Fax 952.835.0430 Email madeline@bergquistcompany.com
Sil-pad 2000	High thermal and dielectric performance. Military/aerospace, commercial applications	0.38 (0.25 to 1.5)	3.5	–60 to +200	Table of typical properties, outgassing data: TML = 0.07%, CVLM = 0.03%. Breakdown voltage: 4kV	Silicone elastomer specially filled	Web www.bergquistcompany.com
Sil-pad K-10	Highest thermal performance of the Bergquist film based insulators. Designed to replace brittle ceramic insulators	0.15	1.3	–60 to +180	Table of typical properties, outgassing data: TML= 0.36%, CVCM = 0.09%. Breakdown voltage: 6 kV	Combination of special Kapton MT polyamide film with a filled silicone rubber	

		Basic Characteristics					
Material	Advantages Application	Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	Manufacturer
Q-pad 3	Thermally/electrically conductive. Grease replacement material where electrical insulation is not required	0.15	2.0	–60 to +180	Table of typical properties	Graphite imbedded in a polymer matrix, fiber glass reinforced	
Therm-gap G974	Electrically nonconductive with high thermal performance. Power conversion, BGA packages, for applications with pressures from 0.03 to 0.69 Mpa	0.25 to 1.5	4.0	–60 to +150	Table of typical properties. Dielectric strength—6 kV/mm	Boron-nitride-filled silicone elastomer	Chomerics Division of Parker Hannifin Corp.
Cho-therm 1671	Low thermal impedance, high dielectric strength. Interfacing between power semiconductor devices and their heat sinks. Military application	0.38	2.6	–60 to +200	Table of typical properties, outgassing data: TML = 0.76%; CVCM = 0.07%. Contact pressure—(2.07–3.55)10^6 N/m^2. Breakdown voltage: 4 kV	Silicone elastomer filled with boron nitride particles	77 Dragon Court, Woburn, MA 01888 USA Tel. 781.935.4850 Fax 781.933.4318
Cho-therm 1678	Thermally conductive elastomer insulators. Electronics, power supplies	0.25	2	–60 to +200	Table of typical properties, outgassing data: TML = 0.55%; CVCM = 0.12%. Contact pressure (2.07–3.55) 10^6 N/m^2. Breakdown voltage: 2.5 kV	Boron nitride filled silicone reinforced with fiberglass	Email mailbox@chomerics.com Web www.chomerics.com

		Basic Characteristics					
Material	Advantages Application	Thick. (mm)	Cond. (W/mK)	Temp. (°C)	Available Technical Data	Structure	Manufacturer
Cho-therm T500	Highly thermally conductive interface insulator. Replacing combination of beryllium oxide or mica wafers and silicone grease.	0.25	2.1	–60 to +200	Table of typical properties, outgassing data: TML = 0.4%; CV CM = 0.1%. Contact pressure—(2.07–3.55)10^6 N/m^2. Breakdown voltage: 5 kV	Combination of silicone binder with a boron nitride filler reinforced with fiberglass	
Sarcon GR-N Series	Highly conformable and high heat conducting electrically insulating materials, easily fit and adhere to most shapes and sizes of components. Used for filling air gaps and uneven surfaces.	1 to 5	7.9	–60 to +200	Table of typical properties	Advanced silicone rubber-gel materials	Fujipoly America Corp. 365 Carnegie Ave. Kenilworth, NJ 07033-0679 USA Tel. 908.298.3850 Fax 908.298.1232 Email frank@fujipoly.com Web www.fujipoly.com
H74/ H77	Low outgassing dispensable pastes for hermetically sealing lids to packages, and general heat dissipation. Aerospace applications		1 to 1.1	150/ 160 max.	Table of typical properties	Two component, alumina filled epoxy	Epoxy Technology, Inc. 14 Fortune Dr. Billerica, MA 01821 USA Tel. 978.667.3805 Fax 978.663.9782 Email sales-info@epotek.com Web www.epotek.com