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Volume resistivity of some insulators at cold temperatures, and electrodless TPC*

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Abstract

We believe that one should control gradients on high voltage insulators using low resistivity plastics. Long-term space charge build-up, especially in a very cold insulator, cannot be excluded if one has a source of charge. Time constants, given extremely large volume resistance values involved, can be extremely long, which can result in quite unusual voltage gradients. Teflon may also shed pollution, which may end up on the cathode wires as a film, which will increase its resistivity in cold liquid, and may lead to a Malter effect.

Measurements of volume resisitivity of various insulators: Figures 1&2 show the experimental setup, which allows a measurement of volume resistivity at LN_2 temperature. Typically we would cool the sample to LN_2 temperature and measure its resistance as it warms up (temperature was monitored by a thermocouple). In this way we could measure temperature dependency. Table 1 shows the summary of measurements. Figure 3 shows that many samples, which have a low resistivity at room temperature, **show an exponential resistivity increase by ~9 orders of magnitude** as one goes from room to LN_2 temperatures. Samples such as Raychem shrinkable tubing, Semitron ESd 490 and PEEK Krefine EKH-SS11 have a relatively low volume resistance at LXe temperature (-109^oC). Many of lower resistivity samples are loaded by carbon. One of them, the Tivitar material, shows a constant resistivity all the way to LN_2 temperature - see Fig.4. Even the Mycalex material, used in CRID as a HV standoff material, has a reasonably small resistivity value at LN_2 temperature, and could be used as HV standoff, if it would not be radioactive. Among lower resistivity samples, there is no one, which would replace Teflon in terms of the photon reflectivity. Many samples, such as Teflon, Polyethylene, Acrylic, etc., have a volume resistance of more than $>4x10^{18}$ Ωcm already at room temperature (limited by a current accuracy of ±0.2 pA and sample thickness). Assuming a similar temperature dependence, their resistance may approach a value of $\rho \sim 10^{27}$ Ωcm at LN_2 temperature. More study is needed in this area to more conducting material, while keeping good reflecting capability Teflon has in the noble liquids.

One should also investigate if Teflon is not shedding either polymer-chain fragments or pollution, coating cathode wire surfaces, and creating a resistive film even before the noble liquid is introduced. This film would then increase its volume resistivity as it is cooled down. Accumulated positive ions sitting on this film may trigger electron emission[1], so called Malter current, well-known effect during wire aging days [3]. The Malter effect needs to be studied in noble liquids as well. One has to do it with exactly the same Teflon

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[*] This note is based on author's contribution to the workshop on "HV issues in noble liquids" held at Fermilab, November 8-9, 2013.

[1] PVC tubing clearly triggered the Malter effect; results with Teflon were less consistent [2]. There are many different types of Teflon sources, so inconsistency is possible.

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as will be used in final TPC.

Electrodless TPC: The Allison's paper [1] was the first one to show the importance of positive ions in the TPC electric field uniformity. As Fig. 5 shows, the simulation indicates that the TPC field has ripples initially when there are no free charges on the insulator surface in between copper strips. Once the positive charge is introduced, ripples are removed, and the deposition of positive ions is self-limiting. Allison used G-10 boards with volume resistivity of $\sim 3\text{x}10^{17}$ Ωcm and surface resitivity of $\sim 10^{15}$ Ω/square (actually manufacturer's values were 1000x smaller, but authors increased based on observed time constants). Reported charging time constant was a few seconds to establish a good field. The positive ions were produced by wire avalanches and charge supplied by plentiful cosmic rays on the surface. The question is what time constants are in a structure where there is no amplification to produce positive ions, it is located deeply underground, and uses Teflon with a volume resistivity of 8 orders of magnitude higher than what Allison used. The ion deposition will be driven by the radioactive source calibration, and whatever cosmic rays penetrate to that depth. What are time constants ? Will it distort the drift field ? This needs to be studied in detail with a laser. So far, none of the noble liquid TPCs equipped with Teflon used such calibration.

On the other hand, one can ask a different question: could one use a carbon-loaded insulator to produce the electrodless TPC operating at LXe temperature. As an example, a TPC made of a 1 m-long, 1 cm-thick, 1 m-radius cylinder using a material #13 in Table 1, would draw ~0.6 nA at 100kV. Such current is too small, i.e., one would have increase the carbon content in this material to get the right current preventing distortions, while not heating of the liquid to form bubbles. For example the sample #18 in Table 1 has too low resistivity. To find the right carbon composition would be very worthwhile R&D effort. A benefit of such a design is that it would eliminate a resistor chain and the electrode grid, and provide a uniform non-localized heating.

Message from old TPC designs: I give an example of CRID TPC [2]: ~20 years ago it was considered essential that both sides of quartz windows have field defining wire electrodes – see Fig.6. To define a stable drift field, potentials were defined on both sides of quartz using Cu-Be electrodes spaced every ~3mm's. In those days, to define potentials only from outside was considered a wrong design, because the quartz would charge up and distort the field inside the TPC. In addition there was additional field cage protecting TPC from external ground of mirrors and liquid radiators. The field cage wires were thick enough to limit the surface field to ~20kV/cm. Similar care was paid to the HV cable. Potentials on the last section of polyethylene insulator were controlled by a low resistivity Raychem shrinkable tubing. This particular material was designed specifically for the charge control a surface charge movement on the insulator. Similarly, the high voltage plane mechanical support used lower-resistivity Mycalex standoffs.

Origin of the paranoia in CRID days was obvious: any corona on the field cage structure or the HV entry (see Fig.6) would shut down the entire CRID TPC system because they were very sensitive to such photons. One should add that we never observed any sign of corona in the HV system.

Concluding remarks: Today's noble liquid TPCs are using a resistive Teflon on the inner side of the active volume. We think that there is a need to investigate long-term charging time constants, and measure drift distortions with a laser. This may tell us how Teflon distributes the charge. One should also investigate if Teflon is not polluting, coating cathode wire surfaces with a film. It is assumed that Teflon coated cathode wires with an insulator, which then may have triggered the Malter electron emission by approaching ions. This effect needs to be studied in noble liquid TPCs as well. One has to do it with exactly the same Teflon as will be used in final TPC.

References:

[1] J. Allison et al., NIM 201(1982)341.
[2] Abe et al., NIMA 343 (1994) 74-86.
[3] J. Va'vra, "Review of wire chamber aging," NIM A252 (1986) 547, and
J. Kadyk, "Wire chamber aging," NIMA 300 (1991) 436.

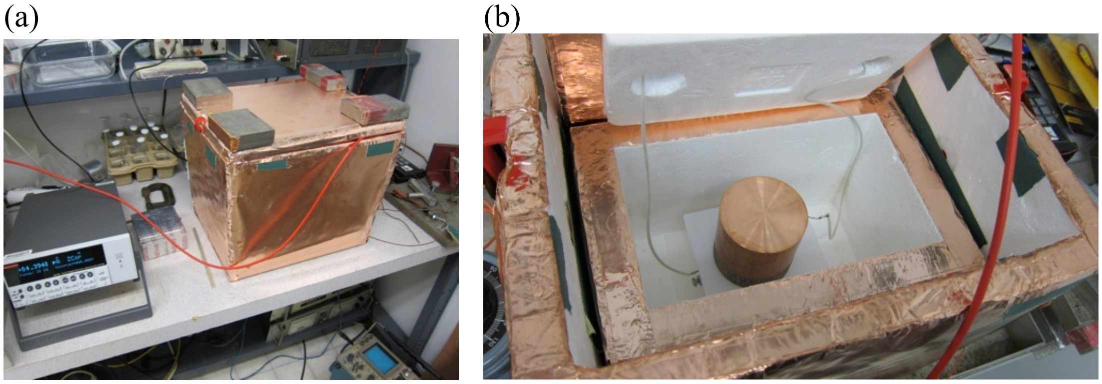


Figure 1: (a) Setup to measure the volume resistivity of samples using the Keithley 6517B instrument. (b) Double-shielded enclosure, LN_2 is put into the inner vessel.

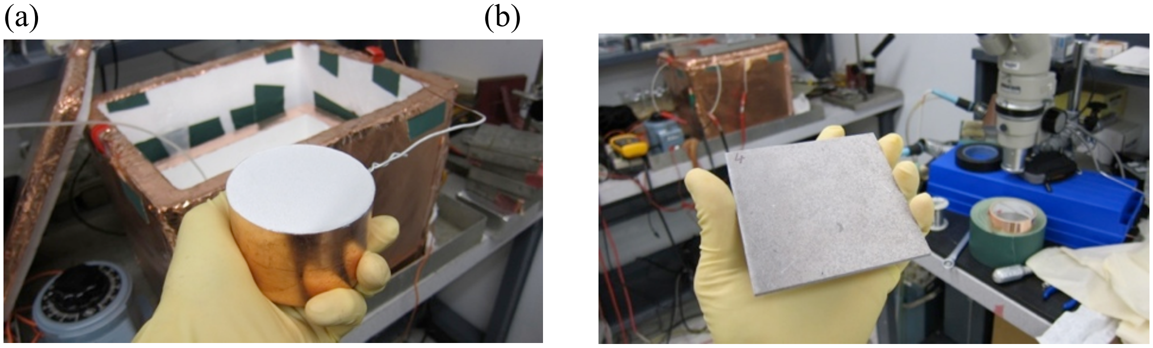


Figure 2: (a) Copper electrodes were plated by ~0.010"-thick Indium to keep a soft contact to the sample even at LN_2 temperature. (d) A typical sample – in this case a sheet of Mycalex.

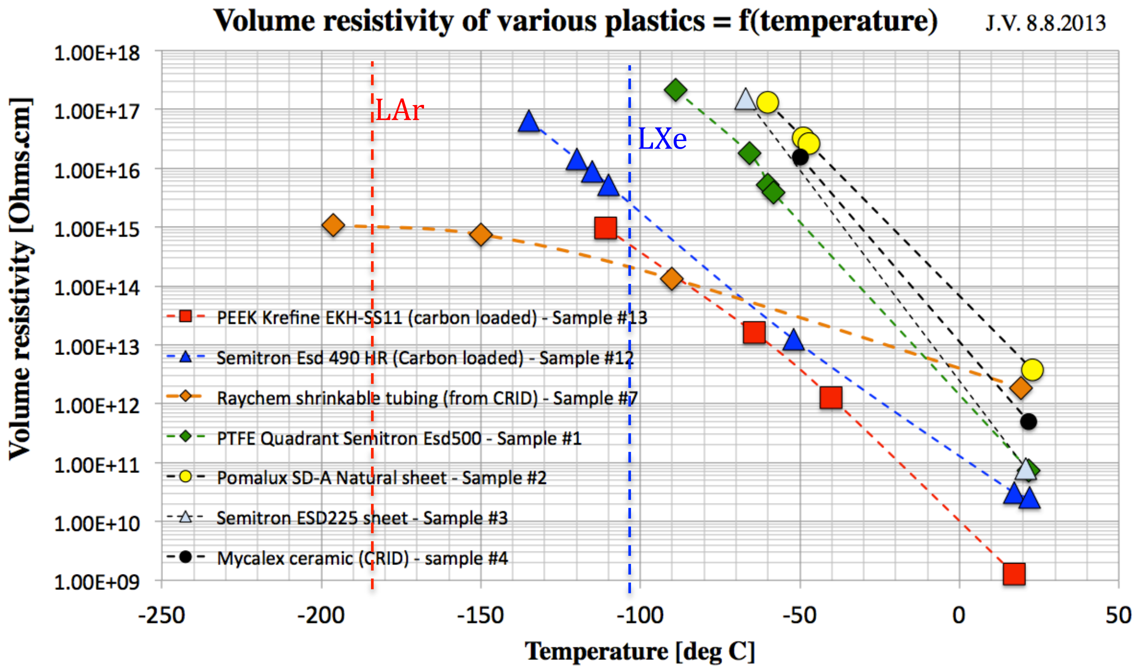


Fig. 3. Resistivity of plastic materials as a function of temperature. There are at least 3 candidates with relatively low resistivity at -109°C.

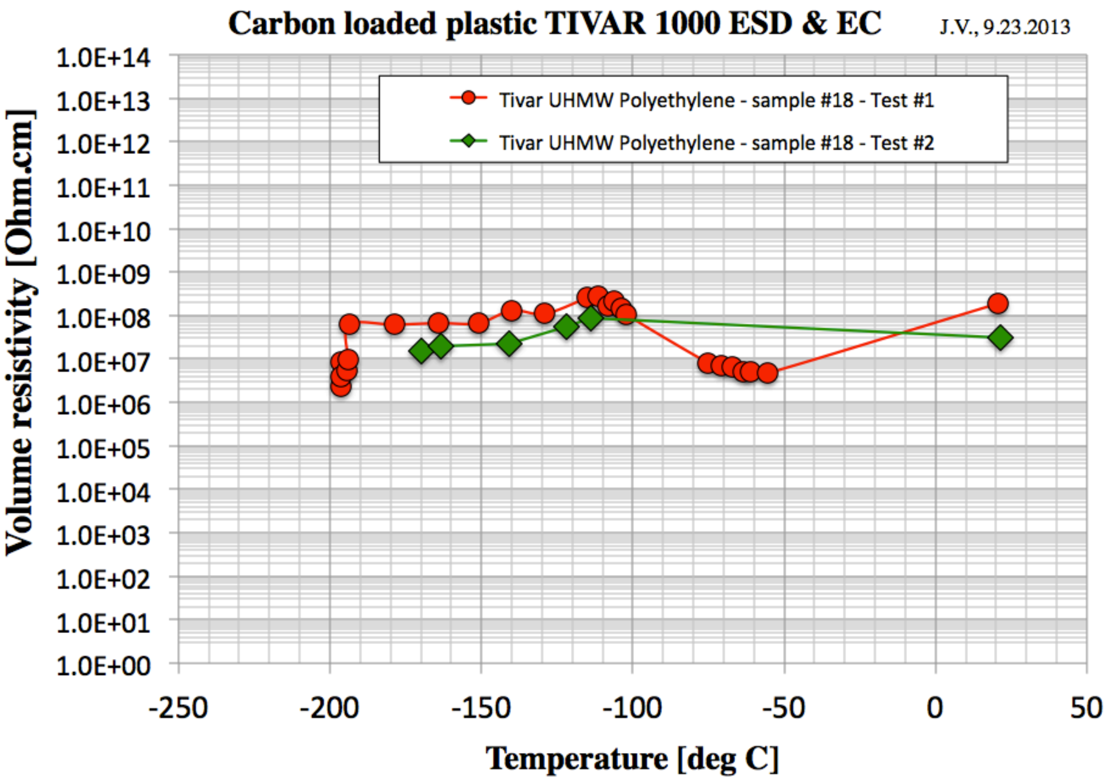


Fig. 4. Resistivity of carbon-loaded TIVAR 1000 ESD & EC plastic. The is a material which has "nearly" constant resistivity all the way to LN_2 temperature.

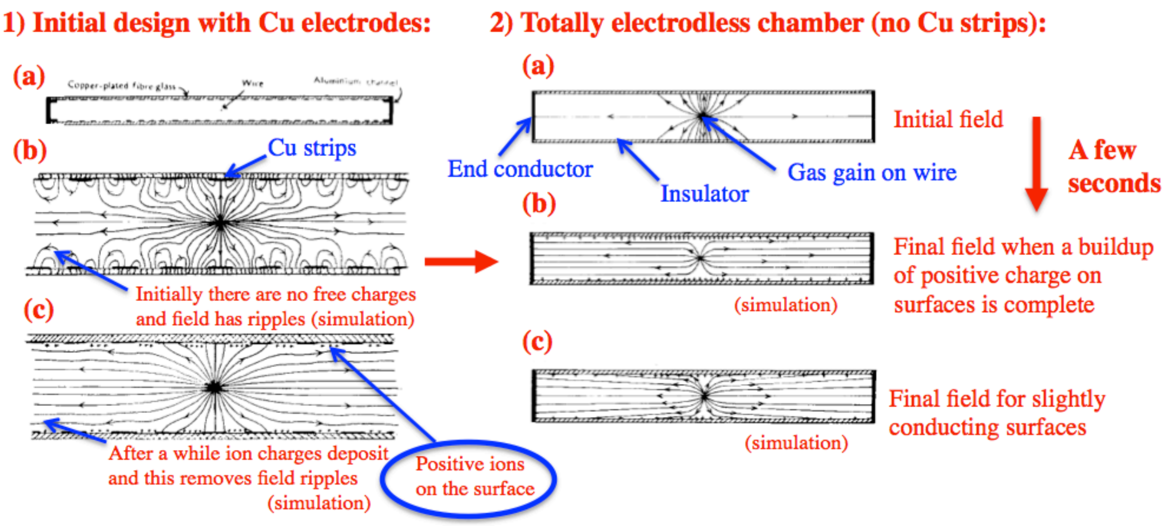


Fig. 5. Allison's paper [1] shows this simulation showing that positive ions play important role to make the drift field uniform: (1b) Drift field has ripples if there no free charges on the G-10 surface between copper strips, (1c) the drift field ripples are removed once positive ions populate these insulator areas; this process is self-limiting. (2a,b,c) electrodless drift chamber. Time constant to go from (2a) state to (2b) state is a few seconds, according to authors.

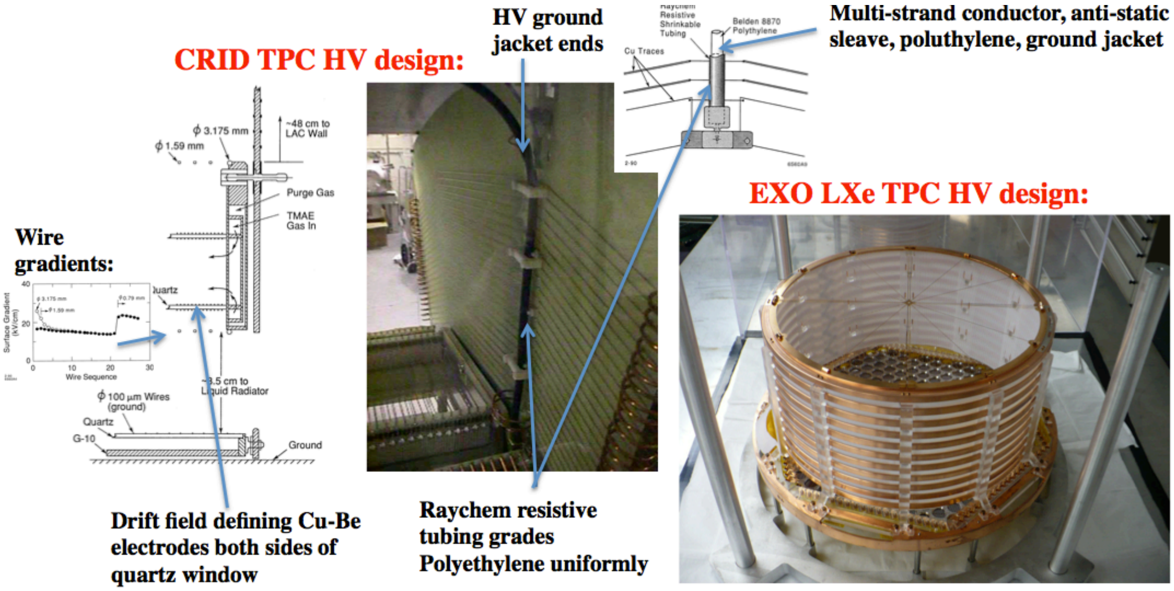
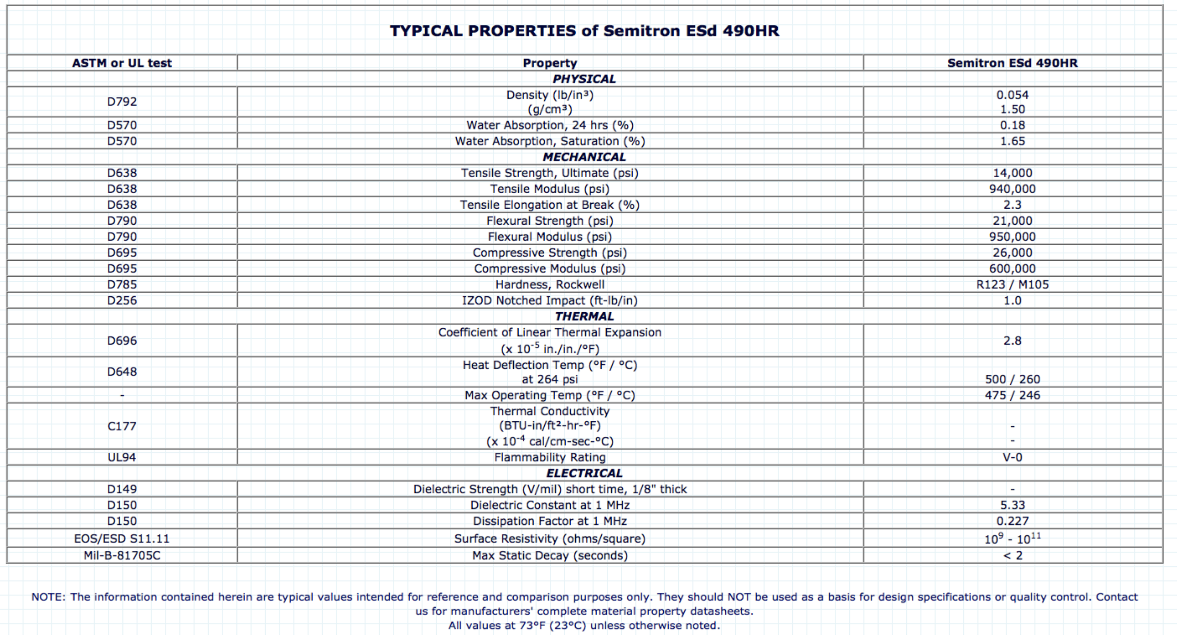


Fig. 6. CRID TPC design shows that quartz had wire electrodes both on inner and outer side of highly resistive quartz windows. This is not done on TPCs such as EXO, LUX, LZ or Darkside-50 where a very highly resistive Teflon is placed inside the active TPC volume.

Table 1: Volume resistivity measurements:
http://www.slac.stanford.edu/~jjv/activity/dark/Vavra_Volume_resistivity_at_cold_temperatures.pdf

Sample	**Material**	**Volume resistivity at room temperature** (all done at 20-21°C) ρ [Ω.cm]	**Volume resistivity at low temperature** (LN$_2$: -196.4°C, LXe: -109°C) ρ [Ω.cm]
1	Semitron ESd 500 (PTFE) (0.29"-thick)	7.5 x 10^{10}	>> 10^{18} at -196.4°C $\geq 10^{18}$ at -109°C
2	Pomalux SD-A natural (0.092"-thick)	3.8 x 10^{12}	>> 10^{18} at -196.4°C >> 10^{18} at -109°C
3	Semitron ESd 225 (0.052"-thick)	8.0 x 10^{10}	>> 10^{18} at -196.4°C >> 10^{18} at -109°C
4	**Mycalex sheet (0.130"-thick)**	**5 x 10^{11}**	**~1.5 x10^{17} at -196.4°C**
5	**Bakelite sheet (0.080"-thick)**	**1.0 x 10^{12}**	**~1.5 x10^{17} at -196.4°C**
6	**Raychem shrinkable tubing from CRID days (0.050"-thick)**	**1.9 x 10^{12}**	**~ 1 x10^{15} at -196.4°C** **~ 3.5 x10^{14} at -109°C**
7	Teflon PTFE (0.030"-thick) - from EXO exp.	> 4 x10^{18}	>> 10^{18} at -196.4°C >> 10^{18} at -109°C
8	Fused silica sheet (0.125"-thick)	~2.2 x10^{18}	>> 10^{18} at -196.4°C
9	Mylar (0.005"-thick)	~2.1 x10^{18}	>> 10^{18} at -196.4°C
10	Acrylic sheet used in EXO test (0.057"-thick)	~4.0 x10^{18}	>> 10^{18} at -196.4°C
11	Raychem, RNF-100-4-BK-STK (0.023"-thick)	~7 x10^{18}	>> 10^{18} at -196.4°C
12	**Semitron ESd 490HR (0.046"-thick) (carbon-loaded)**	**2.6 x 10^{10}**	> 10^{18} at -196.4°C **~ 5.2 x10^{15} at -109°C**
13	**PEEK Krefine EKH-SS11 (0.042"-thick) (carbon-loaded)**	**8.6 x10^{9}**	> 10^{18} at -196.4°C **10^{15} at -109°C**
14	Raychem, MWTM-115/34-1500/U (0.04"-thick)	> 6 x10^{17}	>> 10^{18} at -196.4°C
15	Rexolite (0.035" thick)	>3 x10^{18}	>> 10^{18} at -109°C
16	PVC (0.043" thick)	>3 x10^{18}	>> 10^{18} at -109°C
17	LDPE (0.039" thick)	>3 x10^{18}	>> 10^{18} at -109°C
18	**TIVAR 1000 ESD & EC (0.046" thick) (carbon-loaded)**	**10^{7} - 10^{8}**	**10^{7} - 10^{8} at -196.4°C** **10^{7} - 10^{8} at -109°C**
19	Delrin (0.041" thick)	~5.8 x10^{16}	>> 10^{18} at -109°C
20	Polycarb (0.041" thick)	>3 x10^{18}	-
21	Polypro (0.044" thick)	>3 x10^{18}	-
22	Ultem (0.040" thick)	>3 x10^{18}	-
23	Peek (0.043" thick)	>3 x10^{18}	-
24	Teflon (0.041" thick)	>3 x10^{18}	-
25	Acrylic (0.040" thick)	>3 x10^{18}	-
26	Cast-33 glue (cure 26, TFE) (0.064" thick)	**7.8 x 10^{12}**	>> 10^{18} at -109°C
27	Insul Cast-502 (cure 26,TFE) (0.063" thick)	**1.5 x 10^{16}**	-
28	Lord-340 glue cast (#70, 100-8)	**1.3 x10^{15}**	>> 10^{18} at -109°C
29	CLR-1066/CLH 6330/TEE glue cast	**7 x10^{15}**	-
30	CAST-502 clear clue, Insulcure-26, BYK-A-500	**6.4 x10^{16}**	-
31	Hysol Dexter glue cast (0.057" thick)	**2.5 x10^{15}**	>> 10^{18} at -109°C
32	Sample 2 - unspecified glue cast (0.059" thick)	**2.1 x10^{15}**	-
33	Sample 3 - unspecified glue cast (0.062" thick)	**1.0 x10^{16}**	-
34	Sample 4 - unspecified glue cast (0.059" thick)	**3.3 x10^{15}**	-

Sample #1: SEMITRON® ESd 500HR

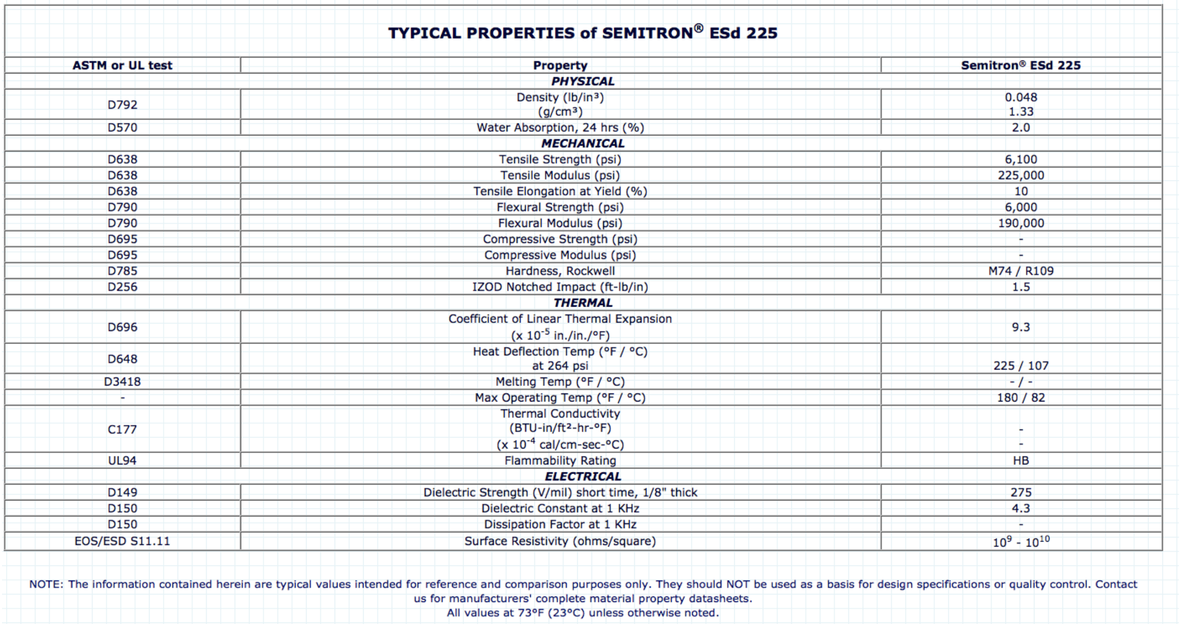


TYPICAL PROPERTIES of Semitron ESd 490HR

ASTM or UL test	Property	Semitron ESd 490HR
	PHYSICAL	
D792	Density (lb/in^3) (g/cm^3)	0.054 1.50
D570	Water Absorption, 24 hrs (%)	0.18
D570	Water Absorption, Saturation (%)	1.65
	MECHANICAL	
D638	Tensile Strength, Ultimate (psi)	14,000
D638	Tensile Modulus (psi)	940,000
D638	Tensile Elongation at Break (%)	2.3
D790	Flexural Strength (psi)	21,000
D790	Flexural Modulus (psi)	950,000
D695	Compressive Strength (psi)	26,000
D695	Compressive Modulus (psi)	600,000
D785	Hardness, Rockwell	R123 / M105
D256	IZOD Notched Impact (ft-lb/in)	1.0
	THERMAL	
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	2.8
D648	Heat Deflection Temp (°F / °C) at 264 psi	500 / 260
-	Max Operating Temp (°F / °C)	475 / 246
C177	Thermal Conductivity (BTU-in/ft^2-hr-°F) (x 10^{-4} cal/cm-sec-°C)	- -
UL94	Flammability Rating	V-0
	ELECTRICAL	
D149	Dielectric Strength (V/mil) short time, 1/8" thick	-
D150	Dielectric Constant at 1 MHz	5.33
D150	Dissipation Factor at 1 MHz	0.227
EOS/ESD S11.11	Surface Resistivity (ohms/square)	10^9 - 10^{11}
Mil-B-81705C	Max Static Decay (seconds)	< 2

NOTE: The information contained herein are typical values intended for reference and comparison purposes only. They should NOT be used as a basis for design specifications or quality control. Contact us for manufacturers' complete material property datasheets.
All values at 73°F (23°C) unless otherwise noted.

Sample #2: Pomalux SD-A natural



TYPICAL PROPERTIES of SEMITRON® ESd 225

ASTM or UL test	Property	Semitron® ESd 225
	PHYSICAL	
D792	Density (lb/in^3) (g/cm^3)	0.048 1.33
D570	Water Absorption, 24 hrs (%)	2.0
	MECHANICAL	
D638	Tensile Strength (psi)	6,100
D638	Tensile Modulus (psi)	225,000
D638	Tensile Elongation at Yield (%)	10
D790	Flexural Strength (psi)	6,000
D790	Flexural Modulus (psi)	190,000
D695	Compressive Strength (psi)	-
D695	Compressive Modulus (psi)	-
D785	Hardness, Rockwell	M74 / R109
D256	IZOD Notched Impact (ft-lb/in)	1.5
	THERMAL	
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	9.3
D648	Heat Deflection Temp (°F / °C) at 264 psi	225 / 107
D3418	Melting Temp (°F / °C)	- / -
-	Max Operating Temp (°F / °C)	180 / 82
C177	Thermal Conductivity (BTU-in/ft^2-hr-°F) (x 10^{-4} cal/cm-sec-°C)	- -
UL94	Flammability Rating	HB
	ELECTRICAL	
D149	Dielectric Strength (V/mil) short time, 1/8" thick	275
D150	Dielectric Constant at 1 KHz	4.3
D150	Dissipation Factor at 1 KHz	-
EOS/ESD S11.11	Surface Resistivity (ohms/square)	10^9 - 10^{10}

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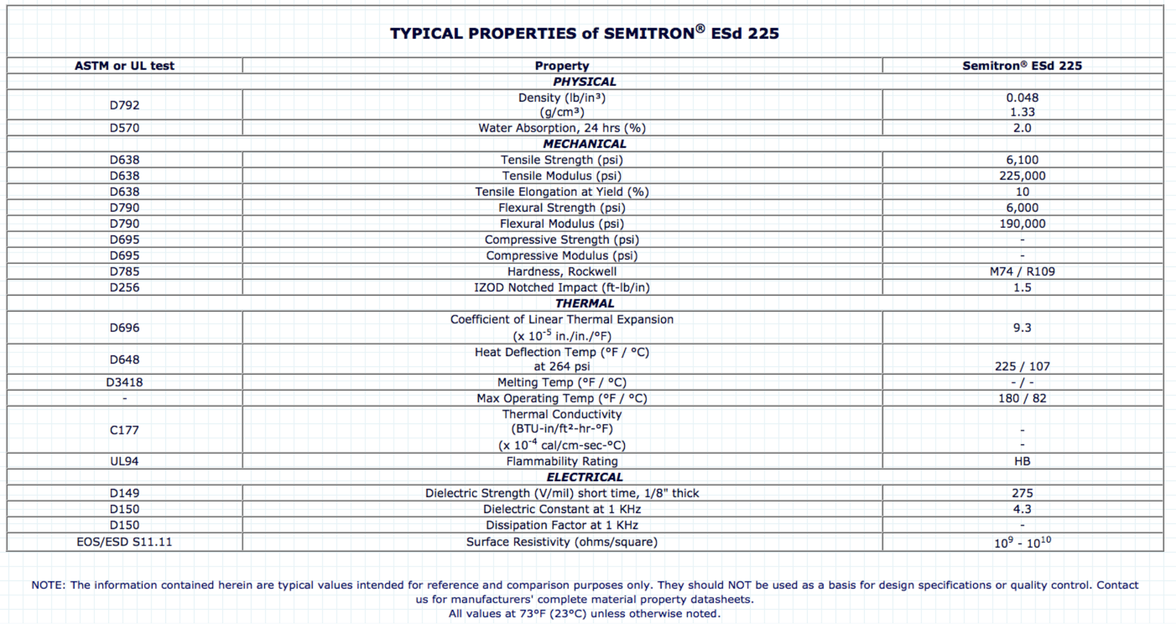
All values at 73°F (23°C) unless otherwise noted.

Sample #3: Semitro ESd 225

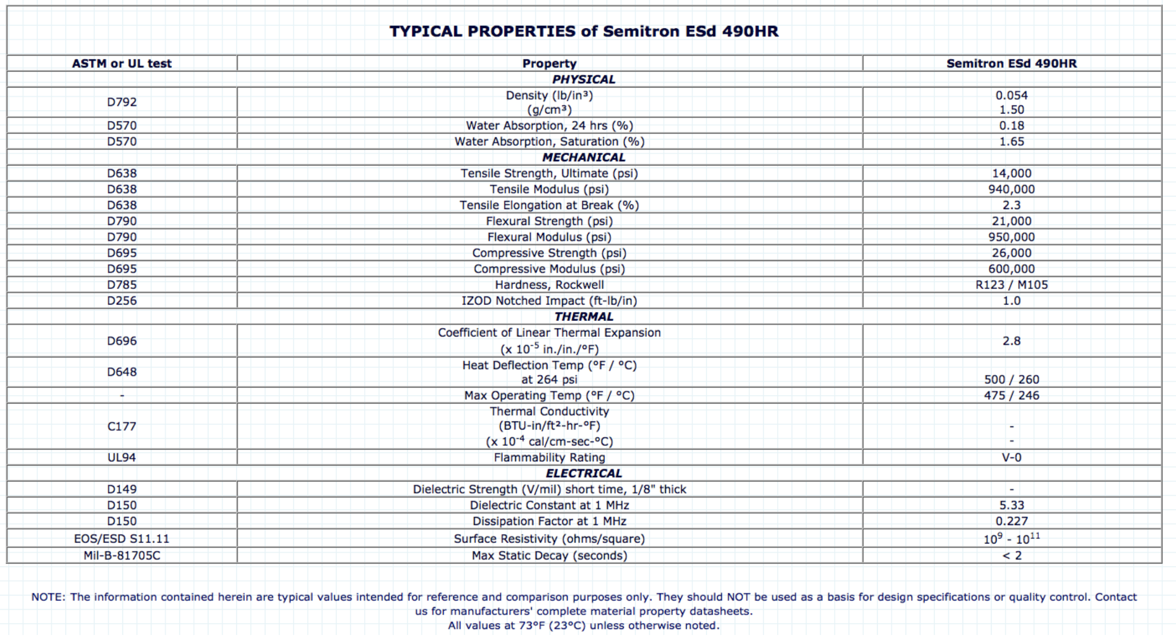


TYPICAL PROPERTIES of SEMITRON® ESd 225

ASTM or UL test	Property	Semitron® ESd 225
	PHYSICAL	
D792	Density (lb/in³) (g/cm³)	0.048 1.33
D570	Water Absorption, 24 hrs (%)	2.0
	MECHANICAL	
D638	Tensile Strength (psi)	6,100
D638	Tensile Modulus (psi)	225,000
D638	Tensile Elongation at Yield (%)	10
D790	Flexural Strength (psi)	6,000
D790	Flexural Modulus (psi)	190,000
D695	Compressive Strength (psi)	-
D695	Compressive Modulus (psi)	-
D785	Hardness, Rockwell	M74 / R109
D256	IZOD Notched Impact (ft-lb/in)	1.5
	THERMAL	
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	9.3
D648	Heat Deflection Temp (°F / °C) at 264 psi	225 / 107
D3418	Melting Temp (°F / °C)	- / -
-	Max Operating Temp (°F / °C)	180 / 82
C177	Thermal Conductivity (BTU-in/ft²-hr-°F) (x 10^{-4} cal/cm-sec-°C)	- -
UL94	Flammability Rating	HB
	ELECTRICAL	
D149	Dielectric Strength (V/mil) short time, 1/8" thick	275
D150	Dielectric Constant at 1 KHz	4.3
D150	Dissipation Factor at 1 KHz	-
EOS/ESD S11.11	Surface Resistivity (ohms/square)	10^{9} - 10^{10}

NOTE: The information contained herein are typical values intended for reference and comparison purposes only. They should NOT be used as a basis for design specifications or quality control. Contact us for manufacturers' complete material property datasheets.
All values at 73°F (23°C) unless otherwise noted.

Sample #12: Semitron ESd 490HR

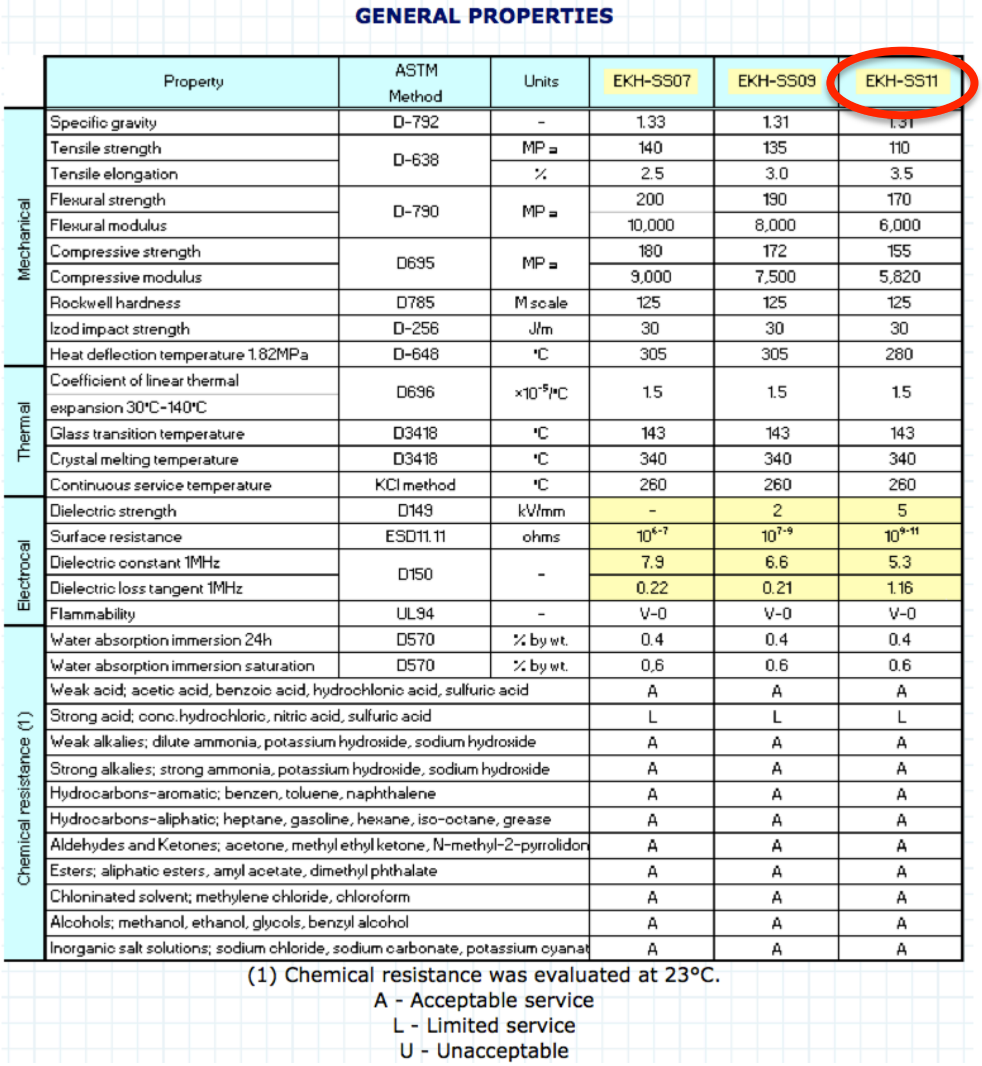


TYPICAL PROPERTIES of Semitron ESd 490HR

ASTM or UL test	Property	Semitron ESd 490HR
	PHYSICAL	
D792	Density (lb/in³) (g/cm³)	0.054 1.50
D570	Water Absorption, 24 hrs (%)	0.18
D570	Water Absorption, Saturation (%)	1.65
	MECHANICAL	
D638	Tensile Strength, Ultimate (psi)	14,000
D638	Tensile Modulus (psi)	940,000
D638	Tensile Elongation at Break (%)	2.3
D790	Flexural Strength (psi)	21,000
D790	Flexural Modulus (psi)	950,000
D695	Compressive Strength (psi)	26,000
D695	Compressive Modulus (psi)	600,000
D785	Hardness, Rockwell	R123 / M105
D256	IZOD Notched Impact (ft-lb/in)	1.0
	THERMAL	
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	2.8
D648	Heat Deflection Temp (°F / °C) at 264 psi	500 / 260
-	Max Operating Temp (°F / °C)	475 / 246
C177	Thermal Conductivity (BTU-in/ft²-hr-°F) (x 10^{-4} cal/cm-sec-°C)	- -
UL94	Flammability Rating	V-0
	ELECTRICAL	
D149	Dielectric Strength (V/mil) short time, 1/8" thick	-
D150	Dielectric Constant at 1 MHz	5.33
D150	Dissipation Factor at 1 MHz	0.227
EOS/ESD S11.11	Surface Resistivity (ohms/square)	10^{9} - 10^{11}
Mil-B-81705C	Max Static Decay (seconds)	< 2

NOTE: The information contained herein are typical values intended for reference and comparison purposes only. They should NOT be used as a basis for design specifications or quality control. Contact us for manufacturers' complete material property datasheets.
All values at 73°F (23°C) unless otherwise noted.

Sample #13: PEEK Krefine EKH-SS11

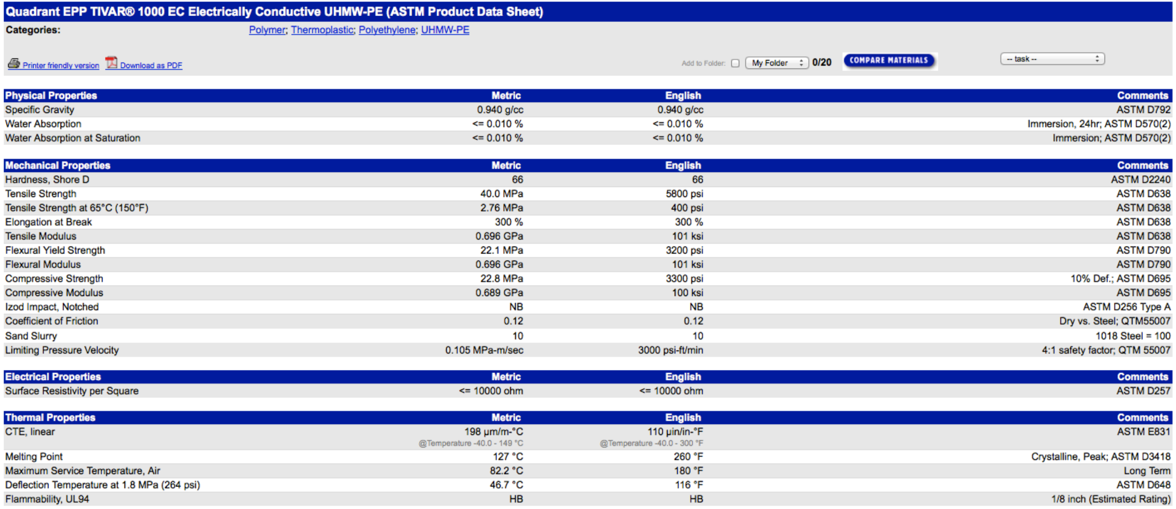


GENERAL PROPERTIES

	Property	ASTM Method	Units	EKH-SS07	EKH-SS09	EKH-SS11
Mechanical	Specific gravity	D-792	-	1.33	1.31	1.31
	Tensile strength	D-638	MPa	140	135	110
	Tensile elongation		%	2.5	3.0	3.5
	Flexural strength	D-790	MPa	200	190	170
	Flexural modulus			10,000	8,000	6,000
	Compressive strength	D695	MPa	180	172	155
	Compressive modulus			9,000	7,500	5,820
	Rockwell hardness	D785	M scale	125	125	125
	Izod impact strength	D-256	J/m	30	30	30
	Heat deflection temperature 1.82MPa	D-648	°C	305	305	280
Thermal	Coefficient of linear thermal expansion 30°C-140°C	D696	$\times 10^{-5}$/°C	1.5	1.5	1.5
	Glass transition temperature	D3418	°C	143	143	143
	Crystal melting temperature	D3418	°C	340	340	340
	Continuous service temperature	KCl method	°C	260	260	260
Electrical	Dielectric strength	D149	kV/mm	-	2	5
	Surface resistance	ESD11.11	ohms	10^{6-7}	10^{7-9}	10^{9-11}
	Dielectric constant 1MHz	D150	-	7.9	6.6	5.3
	Dielectric loss tangent 1MHz			0.22	0.21	1.16
	Flammability	UL94	-	V-0	V-0	V-0
Chemical resistance (1)	Water absorption immersion 24h	D570	% by wt.	0.4	0.4	0.4
	Water absorption immersion saturation	D570	% by wt.	0.6	0.6	0.6
	Weak acid; acetic acid, benzoic acid, hydrochloric acid, sulfuric acid			A	A	A
	Strong acid; conc.hydrochloric, nitric acid, sulfuric acid			L	L	L
	Weak alkalies; dilute ammonia, potassium hydroxide, sodium hydroxide			A	A	A
	Strong alkalies; strong ammonia, potassium hydroxide, sodium hydroxide			A	A	A
	Hydrocarbons-aromatic; benzen, toluene, naphthalene			A	A	A
	Hydrocarbons-aliphatic; heptane, gasoline, hexane, iso-octane, grease			A	A	A
	Aldehydes and Ketones; acetone, methyl ethyl ketone, N-methyl-2-pyrrolidon			A	A	A
	Esters; aliphatic esters, amyl acetate, dimethyl phthalate			A	A	A
	Chloninated solvent; methylene chloride, chloroform			A	A	A
	Alcohols; methanol, ethanol, glycols, benzyl alcohol			A	A	A
	Inorganic salt solutions; sodium chloride, sodium carbonate, potassium cyanat			A	A	A

(1) Chemical resistance was evaluated at 23°C.
A - Acceptable service
L - Limited service
U - Unacceptable

Sample #18: Tivitar 1000 EC



Quadrant EPP TIVAR® 1000 EC Electrically Conductive UHMW-PE (ASTM Product Data Sheet)

Categories: Polymer; Thermoplastic; Polyethylene; UHMW-PE

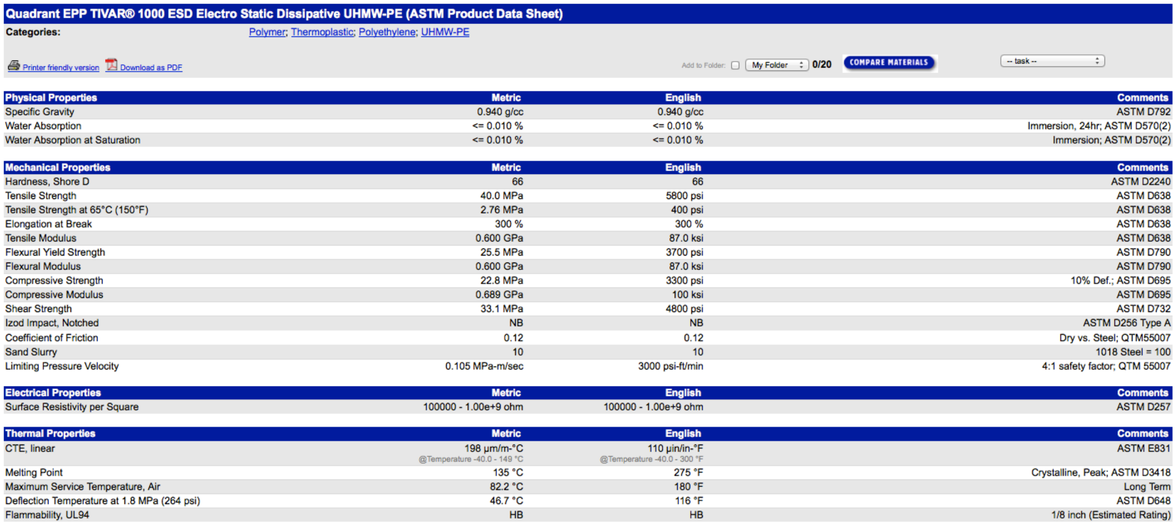
Physical Properties	Metric	English	Comments
Specific Gravity	0.940 g/cc	0.940 g/cc	ASTM D792
Water Absorption	<= 0.010 %	<= 0.010 %	Immersion, 24hr; ASTM D570(2)
Water Absorption at Saturation	<= 0.010 %	<= 0.010 %	Immersion; ASTM D570(2)

Mechanical Properties	Metric	English	Comments
Hardness, Shore D	66	66	ASTM D2240
Tensile Strength	40.0 MPa	5800 psi	ASTM D638
Tensile Strength at 65°C (150°F)	2.76 MPa	400 psi	ASTM D638
Elongation at Break	300 %	300 %	ASTM D638
Tensile Modulus	0.696 GPa	101 ksi	ASTM D638
Flexural Yield Strength	22.1 MPa	3200 psi	ASTM D790
Flexural Modulus	0.696 GPa	101 ksi	ASTM D790
Compressive Strength	22.8 MPa	3300 psi	10% Def.; ASTM D695
Compressive Modulus	0.689 GPa	100 ksi	ASTM D695
Izod Impact, Notched	NB	NB	ASTM D256 Type A
Coefficient of Friction	0.12	0.12	Dry vs. Steel; QTM55007
Sand Slurry	10	10	1018 Steel = 100
Limiting Pressure Velocity	0.105 MPa-m/sec	3000 psi-ft/min	4:1 safety factor; QTM 55007

Electrical Properties	Metric	English	Comments
Surface Resistivity per Square	<= 10000 ohm	<= 10000 ohm	ASTM D257

Thermal Properties	Metric	English	Comments
CTE, linear	198 µm/m-°C @Temperature -40.0 - 149 °C	110 µin/in-°F @Temperature -40.0 - 300 °F	ASTM E831
Melting Point	127 °C	260 °F	Crystalline, Peak; ASTM D3418
Maximum Service Temperature, Air	82.2 °C	180 °F	Long Term
Deflection Temperature at 1.8 MPa (264 psi)	46.7 °C	116 °F	ASTM D648
Flammability, UL94	HB	HB	1/8 inch (Estimated Rating)

Sample #18: Tivitar 1000 ESD



Quadrant EPP TIVAR® 1000 ESD Electro Static Dissipative UHMW-PE (ASTM Product Data Sheet)

Categories: Polymer; Thermoplastic; Polyethylene; UHMW-PE

Physical Properties	Metric	English	Comments
Specific Gravity	0.940 g/cc	0.940 g/cc	ASTM D792
Water Absorption	<= 0.010 %	<= 0.010 %	Immersion, 24hr; ASTM D570(2)
Water Absorption at Saturation	<= 0.010 %	<= 0.010 %	Immersion; ASTM D570(2)

Mechanical Properties	Metric	English	Comments
Hardness, Shore D	66	66	ASTM D2240
Tensile Strength	40.0 MPa	5800 psi	ASTM D638
Tensile Strength at 65°C (150°F)	2.76 MPa	400 psi	ASTM D638
Elongation at Break	300 %	300 %	ASTM D638
Tensile Modulus	0.600 GPa	87.0 ksi	ASTM D638
Flexural Yield Strength	25.5 MPa	3700 psi	ASTM D790
Flexural Modulus	0.600 GPa	87.0 ksi	ASTM D790
Compressive Strength	22.8 MPa	3300 psi	10% Def.; ASTM D695
Compressive Modulus	0.689 GPa	100 ksi	ASTM D695
Shear Strength	33.1 MPa	4800 psi	ASTM D732
Izod Impact, Notched	NB	NB	ASTM D256 Type A
Coefficient of Friction	0.12	0.12	Dry vs. Steel; QTM55007
Sand Slurry	10	10	1018 Steel = 100
Limiting Pressure Velocity	0.105 MPa-m/sec	3000 psi-ft/min	4:1 safety factor; QTM 55007

Electrical Properties	Metric	English	Comments
Surface Resistivity per Square	100000 - 1.00e+9 ohm	100000 - 1.00e+9 ohm	ASTM D257

Thermal Properties	Metric	English	Comments
CTE, linear	198 µm/m-°C @Temperature -40.0 - 149 °C	110 µin/in-°F @Temperature -40.0 - 300 °F	ASTM E831
Melting Point	135 °C	275 °F	Crystalline, Peak; ASTM D3418
Maximum Service Temperature, Air	82.2 °C	180 °F	Long Term
Deflection Temperature at 1.8 MPa (264 psi)	46.7 °C	116 °F	ASTM D648
Flammability, UL94	HB	HB	1/8 inch (Estimated Rating)