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Critical Properties for Selecting Plastic Materials

Scott Williams
Port Plastics

TestConX

Mesa, Arizona • March 5–8, 2023

PORT PLASTICS

Providing Neutral Plastics Expertise to the SEMI Industry

Purpose of the Presentation

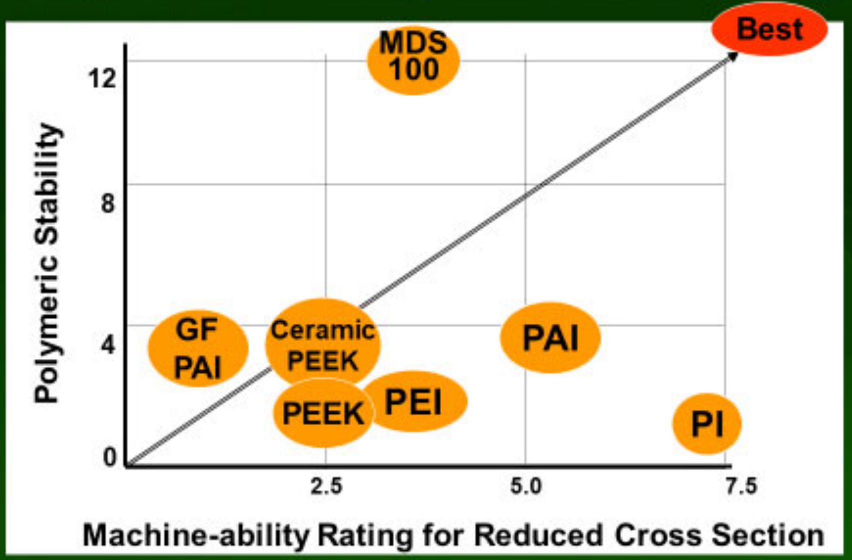
From a materials science perspective, define the data sheet properties critical to optimizing material selection based on the specific applications requirements. Offer theories for each property as to the impact on the test socket application.

Contents

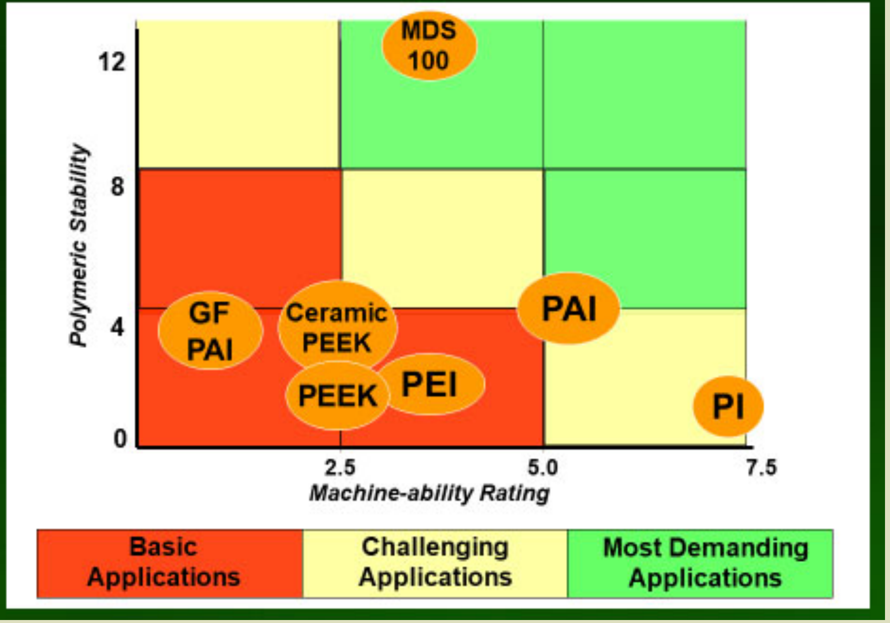
1. Relevant Trends Effecting Plastics Selection
2. The Challenge for Polymer Developers for the Test Industry
3. Properties Critical to Micro Machinability
4. Properties Critical to Stable Applications
5. Summary

Turning Back the Clock to 2009

Polymer Comparison Grid Combining Polymeric Stability w/ Machine-ability



What this means…



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Let's Start With a Typical Data Sheet

- **A typical property datasheet for an engineering thermoplastic resin product contains an extensive list of properties tested since a myriad of industries specify high end materials for machining**
  - ***Oil & Gas***
  - ***Medical***
  - ***Food Processing***
  - ***Aerospace***
  - ***Rail***
  - ***Semiconductor…***
- **It becomes necessary to identify the relevant data markers associated with each specific industry**
- **For the purpose of this paper, we will focus on identifying relevant Thermal, Physical & Mechanical properties for test applications however foregoing Electrical Properties**

Physical Properties	Metric	English	Comments
Specific Gravity	1.27 g/cc	1.27 g/cc	ASTM D 792
Water Absorption	0.25 % @Time 86400 sec	0.25 % @Time 24.0 hour	ASTM D 570
Water Absorption at Saturation	1.25 % @Temperature 23.0 °C	1.25 % @Temperature 73.4 °F	ASTM D 570
Linear Mold Shrinkage, Flow	0.0050 - 0.0070 cm/cm @Thickness 3.20 mm	0.0050 - 0.0070 in/in @Thickness 0.126 in	SABIC Method
Melt Flow	9.0 g/10 min @Load 6.60 kg, Temperature 337 °C	9.0 g/10 min @Load 14.6 lb, Temperature 639 °F	ASTM D 1238

Mechanical Properties	Metric	English	Comments
Hardness, Rockwell M	109	109	ASTM D 785
Tensile Strength, Yield	110 MPa	16000 psi	Type I, 5 mm/min; ASTM D 638
Elongation at Break	60 %	60 %	Type I, 5 mm/min; ASTM D 638
Elongation at Yield	7.0 %	7.0 %	Type I, 5 mm/min; ASTM D 638
Tensile Modulus	3.58 GPa	519 ksi	5 mm/min; ASTM D 638
Flexural Yield Strength	165 MPa	23900 psi	2.6 mm/min, 100 mm span; ASTM D 790
Flexural Modulus	3.51 GPa	509 ksi	2.6 mm/min, 100 mm span; ASTM D 790
Poissons Ratio	0.36	0.36	ASTM E 132
Izod Impact, Notched	0.530 J/cm @Temperature 23.0 °C	0.993 ft-lb/in @Temperature 73.4 °F	ASTM D 256
	13.35 J/cm @Thickness 3.20 mm	25.01 ft-lb/in @Thickness 0.126 in	Reverse Notched; ASTM D 256
Izod Impact, Unnotched	13.35 J/cm @Temperature 23.0 °C	25.01 ft-lb/in @Temperature 73.4 °F	ASTM D 4812
Gardner Impact	36.0 J @Temperature 23.0 °C	26.6 ft-lb @Temperature 73.4 °F	ASTM D 3029
Taber Abrasion, mg/1000 Cycles	10 @Load 1.00 kg	10 @Load 2.20 lb	CS-17; ASTM D 1044

Electrical Properties	Metric	English	Comments
Volume Resistivity	1.00e+17 ohm-cm	1.00e+17 ohm-cm	ASTM D 257
Dielectric Constant	3.15 @Frequency 100 Hz	3.15 @Frequency 100 Hz	ASTM D 150
	3.15 @Frequency 1000 Hz	3.15 @Frequency 1000 Hz	ASTM D 150
Dielectric Strength	19.6 kV/mm @Thickness 3.20 mm	498 kV/in @Thickness 0.126 in	in oil; ASTM D 149
	27.9 kV/mm @Thickness 1.60 mm	709 kV/in @Thickness 0.0630 in	in oil; ASTM D 149
	32.7 kV/mm @Thickness 1.60 mm	831 kV/in @Thickness 0.0630 in	in air; ASTM D 149
Dissipation Factor	0.0012 @Frequency 1000 Hz	0.0012 @Frequency 1000 Hz	ASTM D 150
	0.0015 @Frequency 100 Hz	0.0015 @Frequency 100 Hz	ASTM D 150
	0.0025 @Frequency 2.45e+9 Hz	0.0025 @Frequency 2.45e+9 Hz	ASTM D 150
Arc Resistance	120 - 180 sec	120 - 180 sec	PLC 5; ASTM D 495
Comparative Tracking Index	100 - 175 V	100 - 175 V	PLC 4; UL 746A
Hot Wire Ignition, HWI	60 - 120 sec	60 - 120 sec	PLC 1; UL 746A
High Amp Arc Ignition, HAI	15 - 30 arcs	15 - 30 arcs	PLC 3; UL 746A
High Voltage Arc-Tracking Rate, HVTR	25.4 - 80.0 mm/min	1.00 - 3.15 in/min	PLC 2; UL 746A

Thermal Properties	Metric	English	Comments
CTE, linear, Parallel to Flow	55.8 µm/m-°C @Temperature -20.0 - 150 °C	31.0 µin/in-°F @Temperature -4.00 - 302 °F	ASTM E 831
CTE, linear, Transverse to Flow	54.0 µm/m-°C @Temperature -20.0 - 150 °C	30.0 µin/in-°F @Temperature -4.00 - 302 °F	ASTM E 831
Thermal Conductivity	0.220 W/m-K	1.53 BTU-in/hr-ft²-°F	ASTM C 177
Deflection Temperature at 0.46 MPa (66 psi)	210 °C @Thickness 6.40 mm	410 °F @Thickness 0.252 in	unannealed; ASTM D 648
Deflection Temperature at 1.8 MPa (264 psi)	201 °C @Thickness 6.40 mm	394 °F @Thickness 0.252 in	unannealed; ASTM D 648
Vicat Softening Point	218 °C	424 °F	Rate B/50; ASTM D 1525
Glass Transition Temp, Tg	217 °C	423 °F	
UL RTI, Electrical	170 °C	338 °F	UL 746B
UL RTI, Mechanical with Impact	170 °C	338 °F	UL 746B
UL RTI, Mechanical without Impact	170 °C	338 °F	UL 746B
Flammability, UL94	V-2 @Thickness 0.400 mm	V-2 @Thickness 0.0157 in	UL 94
	V-0 @Thickness 0.750 mm	V-0 @Thickness 0.0295 in	UL 94
	5VA	5VA	UL 94

Industry Trends Effecting Plastic Selection in Test Applications

	Wafer Size	Node Size	Interesting Tidbits
1960s	• 13 mm in 1960 • 25 mm in 1964		• Moore's Law in 1965, the number of components per IC double each yr • 600 transistors in 100 Bit chip
1970s	• 30 mm in 1970 • 125 mm in 1979	10 µm – 1971 3 µm - 1975	• 2300 transistors in 1971 • 29,000 transistors in 1979
1980s	• 150 mm in 1981	1 µm – 1985 800nm - 1989	• 134,000 transistors in 1981 • 275,000 transistors in 1985
1990s	• 300 mm in 1996	600nm – 1994 250nm - 1998	• 1993 3.1 Million transistors – Pentium • 1999 29 Million transistors – Pentium III
2000s	• No Change	180nm – 2000 90nm – 2003 45nm – 2007	• 2005 169 Million transistors – Pentium 4 • 2009 800 Million transistors!!! – Core II Duo
2010-2023	•300mm still!	32nm – 2010 22nm – 2011 14nm – 2015 10nm - 2017 7nm - 2019 5nm – 2020 3nm - 2022	• The beginning of nanoelectronics • Use of hi-k metals means no conventional • Implementation of 5G in 2019 • TSMC leads the way with 3 nano chip *technology*

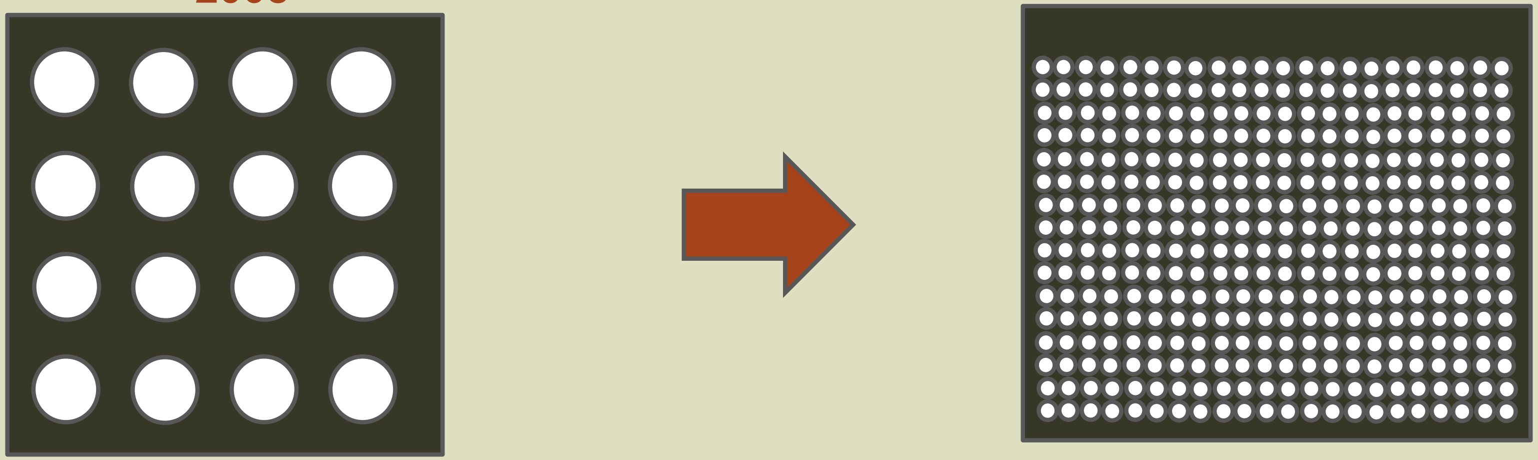
Year	Node Size
2000	130 nm
2003	90 nm
2006	65 nm
2009	45 nm
2012	28 nm
2015	14 nm
2019	7 nm
2023	5 nm

Hole Size	Material Stiffness
0.8 mm	420,000
0.6 mm	500,000
0.4 mm	600,000
0.25 mm	980,000
0.18 mm	1,000,000
0.1 mm	1,250,000
0.08 mm	1,400,000
??	Next Generation?

Miniaturization Plays a Major Role in the Design of Burn In & Test Applications

The Effect of Miniaturization on the Test Socket Industry

2008 → 2020



2008	2020
Chip Set : Intel CORE i3	**Chip Set : Apple A12 Bionic**
Node Size 45 nanometer	**Node Size 7 nanometer**
Socket Hole Size – 0.4mm	**Socket Hole Size – 0.08mm**
Socket Pitch Size - 1.0mm	**Socket Pitch Size - 0.10mm**
Socket Wall Size – 0.6mm	**Socket Wall Size – 0.02mm**

Clearly the same material does not work for these applications

The Balance Between the Two Top Level Critical Parameters

Micro-Machinability

- Defined as the ability to successfully machine features that:
  - Are aggressive in their micro size and repetition
  - Require precision placement at tolerances seemingly impossible for plastics
  - That require clean features such as burr-free micro holes

Stability of the Finished Application

- Defined as the realization of a finished application that will best hold its dimensional stability over a wide range of test parameters such as:
  - Resistance to flexing under load given
  - Resistance to growth over a wide temperature range
  - Resistance to growth due to excessive moisture absorption

Key Point - Traditionally the Rheological Development of Materials to Achieve Increased Dimensional Stability Results in Materials That Are More Difficult to Micro-Machine

Let's look at the properties that influence each parameter

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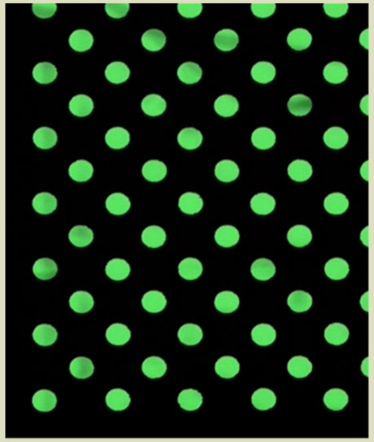
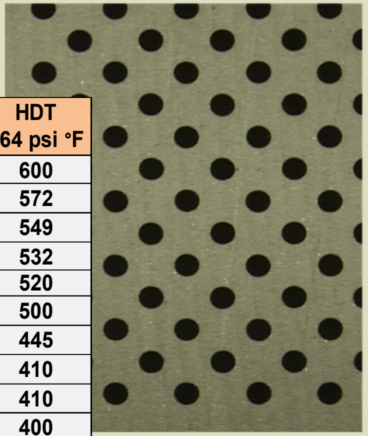
Micro-Machinability Critical Property Number ONE
Glass Transition Temperature & Melt Temperature

MCAM Kyron® GC-100
0.08 mm hole size





- When an amorphous polymer is heated, the temp at which the polymer structure turns to “a rubbery state" is called the Glass Transition Temp.
  ~PAI Torlon – Ultem PEI~
- Melt Temperature is defined as the temperature of which a crystalline material falls out of its crystalline structure and becomes a liquid phase.
  ~ PEEK – Polyimide ~

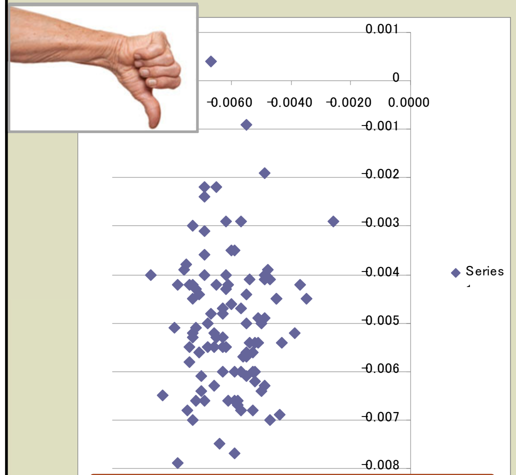
As it Relates to Micro-Machinability in Test Sockets

- Micro hole drilling involves high speeds & extremely small drill bits that generate a high level of surface frictional heat
- The higher the thermal resistance of a material the cleaner the hole upon exit of the drill bit
- Techniques that can improve the burring condition

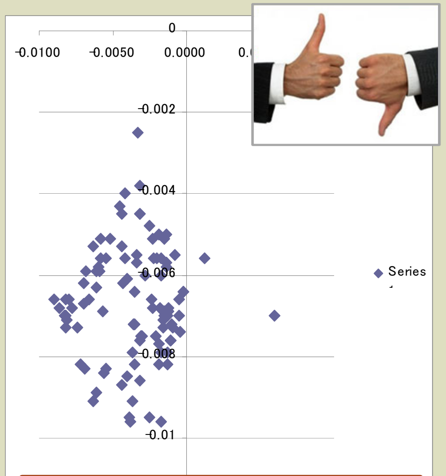
Polymer	Temp ºF	Tg MP	HDT 264 psi °F
Standard Polyimide	900+	Melt	600
Ensinger TECAPEEK® CMF	643	Melt	572
MCAM Kyron® 2204	649	Melt	549
Torlon PAI	527	Tg	532
Torlon 30% GF	527	Tg	520
MCAM Semitron® MP-370	649	Melt	500
MCAM Kyron® GC 100	649	Melt	445
MCAM Semitron® MDS-100	600	Melt	410
PEI (Ultem) + Glass	410	Tg	410
Ultem 1000 (PEI)	410	Tg	400
GP PEEK	649	Melt	320

Micro-Machinability Critical Property # TWO - Tensile Elongation

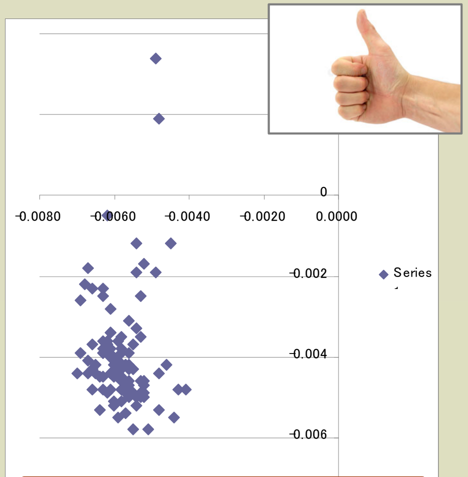
- **Tensile Elongation at Break *(ASTM D412)* is a measure of a materials ductility expressed in percent stretch before break. Low ductility refers to a brittle material while high ductility equates to a material that is generally stretchable**
- **Testing on the capability to *Place Holes With Accuracy* show that the lower the ductility or the more brittle the material, the better the material for precision hole placement**



Tensile Elongation – 10%



Tensile Elongation – 7%



Tensile Elongation – 3%

	Tensile Elongation
MCAM Semitron® MDS-100	1.3
MCAM Kyron® GC-100	3
MCAM Semitron® MP370	3
Ensinger TECAPEEK® CMF	4
PAI 30% GF	4
DuPont Vespel® SP-1	7.5
DuPont Vespel® SCP -5000	7.5
Ensinger TECAPEEK® TV-20	8
Torlon 4203	10
MCAM Kyron® 2204	21
PEEK natural	40
Ultem 1000	60

Micro-Machinability Critical Property # THREE - Filled Materials

- Fiber fillers have long been used in plastics to enhance mechanical strength properties such as Flexural Modulus

➢ *Carbon Fiber Filled – expensive, reduce weight, strength*
➢ *Glass Fiber Filled – low cost method to increase strength*

	Virgin Resin	30% Glass Filled
PEEK	600,000 psi	900,000 psi
Torlon PAI	600,000 psi	980,000 psi
Ultem PEI	500,000 psi	850,000 psi

Flexural Modulus of Elasticity @ 73°F

- Carbon Fiber Materials have low potential for use in Test applications due to contamination & they exhibit conductive properties

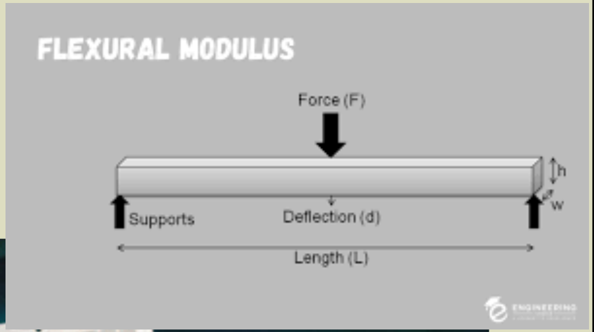
- Glass Fiber filled materials are used for lower cost high strength applications that do not require precision micro hole machining

- Ceramic micro-powders are used in virgin resins such as PEEK to add stiffness & dimensional stability to resin matrix with much better micro-machinability than glass filled materials

	Virgin PEEK	Standard Ceramic Filled PEEK	Semitron GC-100 CF PEEK
Flexural Modulus	600,000 psi	783,000 psi	1,100,000 psi
CTE	2.6	2.0	1.9
Tensile Elongation	40%	3%	3%

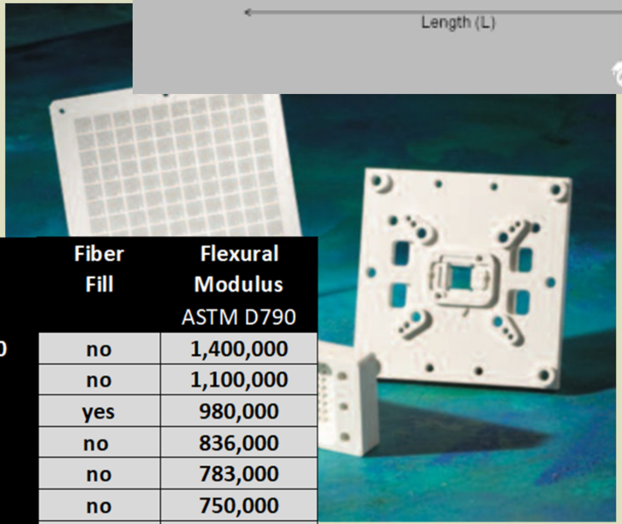
Stable Application Critical Property Number ONE - Flexural Modulus

- Flexural Modulus of Elasticity (ASTM D790) is a measure of a materials ability to resist bending or the materials stiffness.
- Specifically it is a measurement of stress to corresponding strain, expressed in PSI



Relevance to Test Applications

- Driven by increasing hole counts in array patterns, decreasing pitch sizes & decreasing material between holes coupled with decreasing cross sections
- ~75%+ of the material can be machined away with cross sections in the 1mm range, the higher the Flexural Modulus, the more likely the material will maintain stiffness in use



	Fiber Fill	Flexural Modulus ASTM D790
Semitron® MDS-100	no	1,400,000
Kyron® GC-100	no	1,100,000
PAI 30% GF	yes	980,000
Vespel® SCP -5000	no	836,000
TECAPEEK® CMF	no	783,000
Kyron® 2204	no	750,000
PEEK natural	no	630,000
Semitron® MP370	no	625,000
Torlon 4203	no	600,000
Ultem 1000	no	500,000
Vespel® SP-1	no	450,000

Stable Application Critical Property Number TWO - Moisture Absorption

- Moisture Absorption in plastics (ASTM D570) measures the weight gain of a plastic specimen at 23°C at 24 hours and to saturation
- *The relevance to test applications is the isotropic growth of the application after machining due to exposure to humidity*

	Moisture 24 hours ASTM D570
Semitron® MDS-100	0.1
TECAPEEK® LP TV20	0.08
Kyron® GC-100	0.09
PAI 30% GF	0.3
Vespel® SCP -5000	0.1
TECAPEEK® CMF	0.06
Kyron® 2204	0.37
PEEK natural	0.1
Semitron® MP370	0.1
Torlon 4203	0.4
Ultem 1000	0.25
Vespel® SP-1	0.24

So what do we know about Moisture Absorption & Plastics?

Two mechanisms a plastic material will absorb & maintain moisture:

1) **Micro porosity** – nano sized pockets in the plastic that has the ability to absorb moisture, the water exists within a free state. Represents more than 90% of the moisture in a typical polymer.

2) **Immobilized Moisture** – water molecules have a tendency to form hydrogen bonds, water may chemically react with the polymer making a non free state.

The rate of moisture absorption can be accelerated by increasing the temperature, however the capacity at saturation will not change significantly

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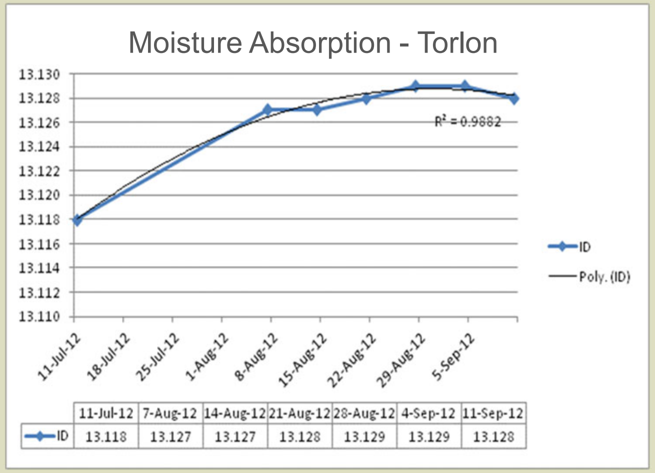
Practical Thoughts About Moisture Absorption

- The high end materials are often annealed after processing to reduce stress levels, resulting in a dry starting point
- The imidized materials (Torlon PAI & Polyimides) are post cured at extreme temps for extended time
- An artificially dry moisture materials are highly motivated to reach equilibrium within the environment they are in
- Materials reach equilibrium within the environment they are in which is between dry and saturation, equilibrium is desired to minimize growth
- Water immersion = 2X absorption rate vs. ambient air (23°C, 50%RH)
- Temps over 100°C are required to drive water out of the material



	Water (Saturation in QC Lab)				Ambient Air (Tech Center)				Saturation	Air
	Ring 1	Ring 2	Ring 3	Ring 4	Ring 5	Ring 6	Ring 7	Ring 8	Average	Average
Week 1 Difference	0.0030	0.0016	0.0026	0.0029	0.0042	0.0035	0.0029	0.0024	0.0025	0.0033
Week 2 Difference	0.0055	0.0039	0.0057	0.0043	0.0037	0.0031	0.0033	0.0032	0.0049	0.0033
Week 3 Difference	0.0061	0.0037	0.0057	0.0049	0.0037	0.0045	0.0039	0.0035	0.0051	0.0039
Week 4 Difference	0.0053	0.0032	0.0069	0.0054	0.0058	0.0070	0.0052	0.0050	0.0052	0.0058
Week 5 Difference	0.0068	0.0051	0.0091	0.0064	0.0048	0.0047	0.0038	0.0056	0.0068	0.0047
Week 6 Difference	0.0081	0.0059	0.0088	0.0067	0.0048	0.0047	0.0043	0.0058	0.0074	0.0049
Week 7 Difference	0.0082	0.0060	0.0092	0.0069	0.0063	0.0055	0.0050	0.0058	0.0076	0.0056
Week 8 Difference	0.0095	0.0065	0.0092	0.0083	0.0056	0.0085	0.0063	0.0053	0.0084	0.0064
Week 10 Difference	0.0096	0.0076	0.0094	0.0089	0.0041	0.0077	0.0046	0.0044	0.0089	0.0052
Week 12 Difference	0.0115	0.0090			0.0067	0.0055			0.0102	0.0061
Week 14 Difference	0.0136	0.0106			0.0046	0.0051			0.0121	0.0049
Week 16 Difference	0.0129	0.0110			0.0049	0.0060			0.0119	0.0055

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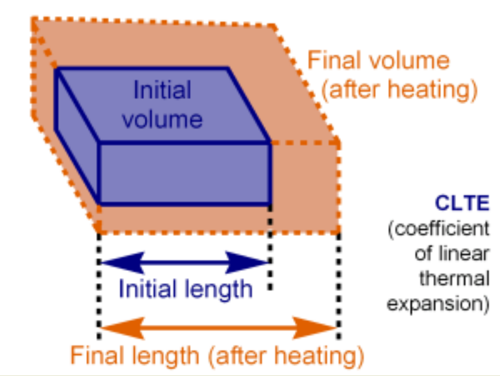
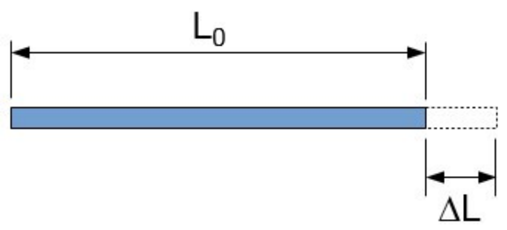
Stable Application Critical Property Number THREE - CTE

- Coefficient of Thermal Expansion (CTE) is the measure of the change in length or volume per unit rise in temperature
- Coefficient of Linear Thermal Expansion (CLTE) is the measure of change in length per unit rise in temperature
- Plastic materials have their own unique Coefficient of Linear Thermal Expansion "α" ~ $\Delta L = L_0 \bullet \alpha \bullet (T_1 - T_0)$
- For Engineering Thermoplastics -30°F to 300°F (-30°C to 149°C) is a common range for testing, CLTE measured by in./in./°F.
- Isotropic plastics such as amorphous plastics expand equally in all directions (X, Y & Z) when applied to thermal energy.
- The volumetric expansion coefficient (X,Y & Z) is approx. 3X the linear expansion coefficient

CTE

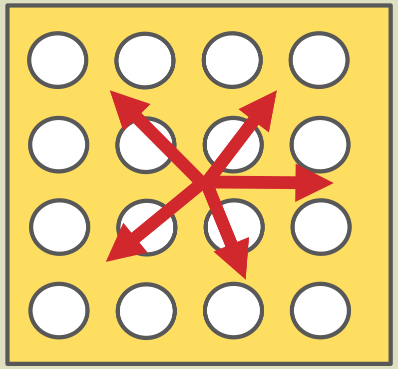


CLTE

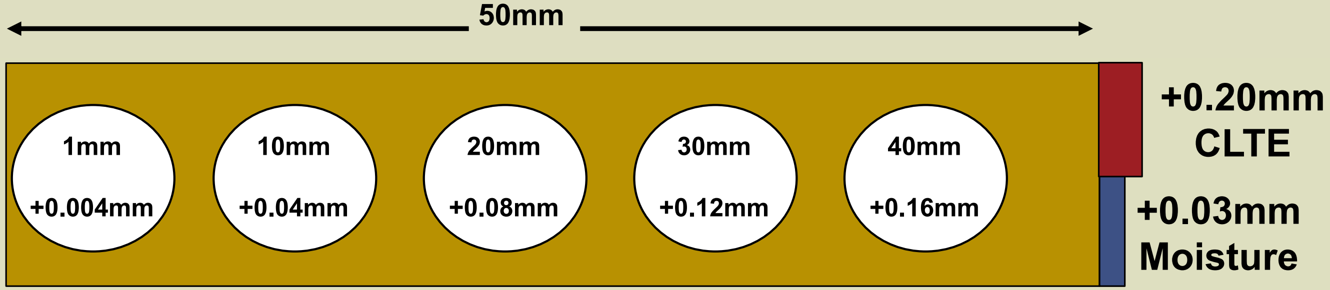


The Relevance of CTE to Test Socket Applications

- Test Applications subjected to testing over a wide temperature range of can have a significant impact of placement of the holes
- For unsecured applications, growth is generally from the middle of the part out in all directions (X,Y and Z) .
- Finished socket growth can be impacted from both CTE & Moisture absorption and thus need to be considered

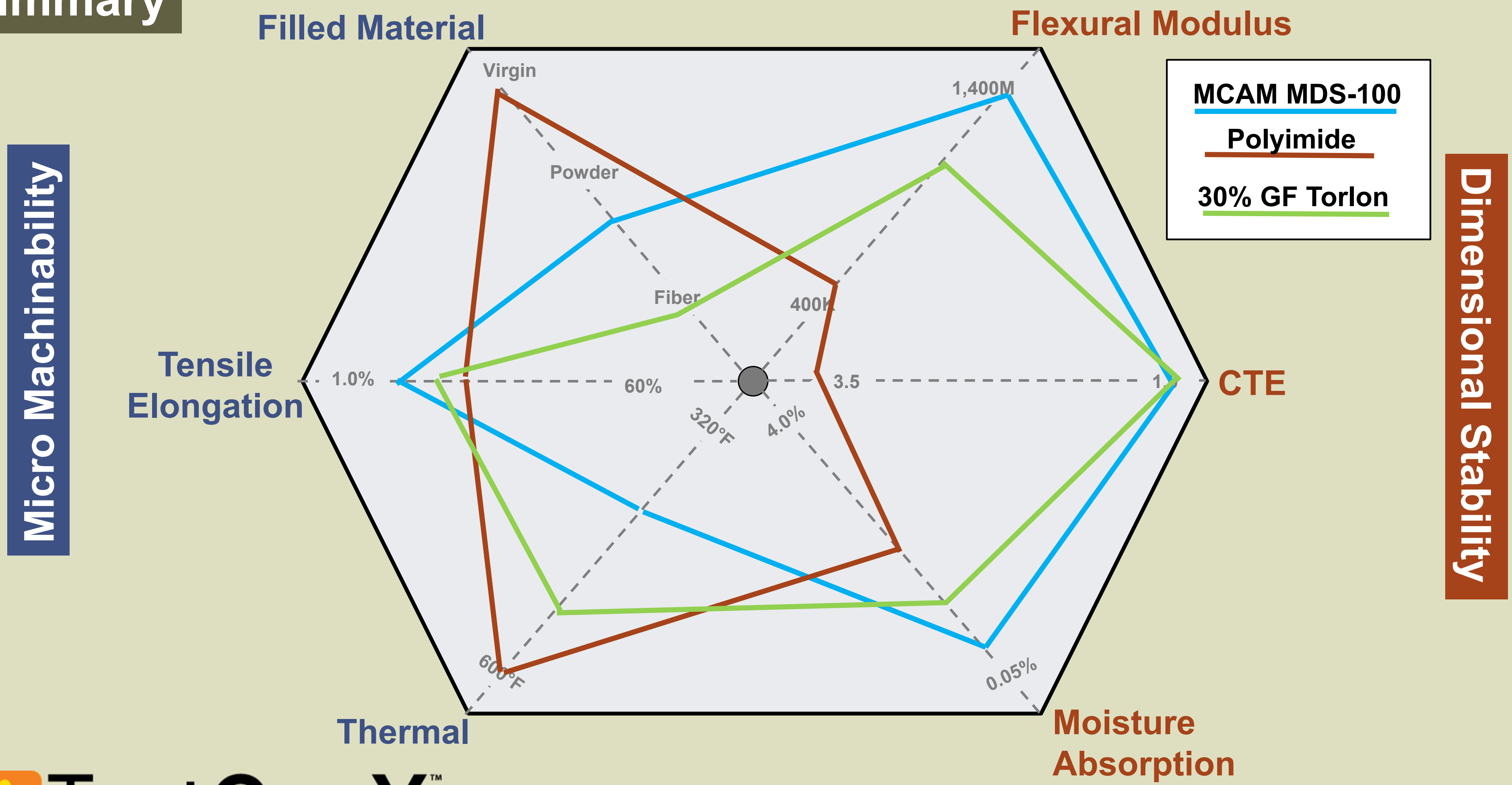


CLTE vs Moisture Absorption for PEEK *(0°F to 150°F)*



	CTE *(X 10^-5)* *ASTM D831*
Semitron® MDS-100	1.1
TECAPEEK® LP TV20	1.9
Kyron® GC-100	1.9
PAI 30% GF	0.9
Vespel® SCP -5000	2.6
TECAPEEK® CMF	3.1
Kyron® 2204	2
PEEK natural	2.6
Semitron® MP370	2.5
Torlon 4203	1.7
Ultem 1000	3.1
Vespel® SP-1	3.05

Summary


Micro Machinability
Filled Material
Virgin
Powder
Fiber
Tensile Elongation
1.0%
60%
Thermal
320°F
600°F
Flexural Modulus
1,400M
400K
CTE
3.5
1.
Moisture Absorption
4.0%
0.05%
MCAM MDS-100
Polyimide
30% GF Torlon
Dimensional Stability