MOISTURE EFFECTS IN COMMON SOLDERABLE RF CONNECTOR DIELECTRICS

Jeffrey Marcus Jennings
Harris Corporation
Melbourne, FL, USA
jjenni02@harris.com

ABSTRACT

Control of moisture exposure and proper application of drying methods during the surface mount assembly process are essential to prevent moisture-related damage from soldering operations. For many component types (non-hermetic surface mount devices (SMD), non-integrated circuit (IC) electrical components, etc.), the handling, storage, and drying process are clearly specified (see IPC/JEDEC J-STD-020, -033 & -075). Unfortunately, the guidance these specifications provide for electrical connectors is less definitive despite some of their constituent materials potentially exhibiting similar moisture-related soldering process incompatibilities. In addition, these specifications exclude manual soldering operations, referred to as "Point to Point" and wave soldering, which are more commonly used during connector installation. The potential for moisture-related damage is particularly concerning for radio frequency (RF) connector polymeric dielectrics which often are selected based on their electrical performance characteristics rather than their processing robustness. In the current study, the tendencies of various commonly used RF connector polymeric materials to absorb and desorb moisture under various humidity and temperature conditions are characterized with the impact of sample size effects on these properties being considered. Differences in the dimensional stability of these materials during soldering temperatures in a moisture saturated versus dried condition are compared utilizing thermomechanical analysis (TMA). The materials are then exposed to various soldering process conditions, such as convective reflow, and solder pot dip to qualitatively identify any potential process incompatibilities. These results are then used to classify the relative "process" and "moisture sensitivity levels" for the various materials evaluated and provide recommendations for any special moisture-related handling, storage, and drying conditions for solderable connectors containing these materials.

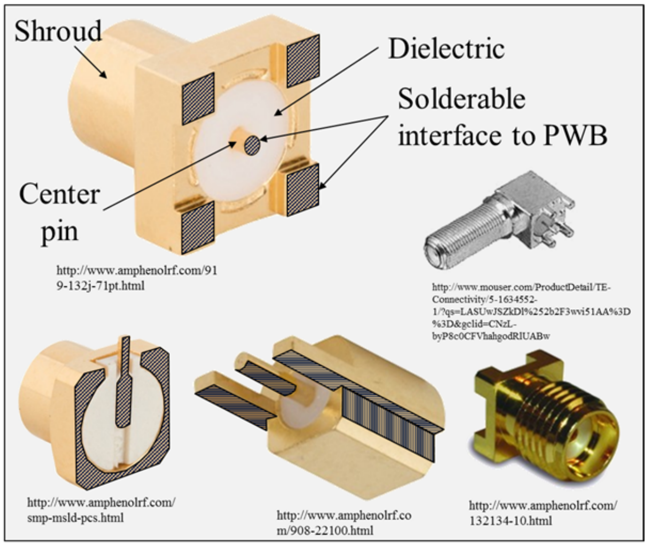
Key words: moisture effects & humidity exposure control, soldering, process compatibility, RF connector dielectrics, thermoplastics, material characterization

INTRODUCTION

Moisture level control for electronic components and printed wiring boards is an integral part of the surface mount technology (SMT) assembly (or solder reflow) process. Many of the polymeric materials used in electronic component construction (epoxies, thermoplastics, silicones, etc.) are hygroscopic in nature. As a result, they absorb moisture when exposed to humidity, like that present in a manufacturing facility's ambient environment. The moisture content achieved within these materials depends on several factors including: the temperature/humidity conditions; duration of exposure; material type; and geometry (1). As the absorbed moisture level increases, the polymeric materials undergo changes in physical properties including: reduced adhesion strength; decreased stiffness (at higher temperatures); lowered glass transition temperature; and increased expansion rate over temperature (2). The deleterious impact of these changes is often realized during the elevated, rapidly transitioning temperature conditions of the solder reflow process. The increased temperature supplies sufficient kinetic energy to free water molecules unable to diffuse out of the material quickly enough, converting them into a gaseous phase that applies pressure on the surrounding material which can lead to blistering or "popcorn" failure when that pressure exceeds the strength of the surrounding material[s] (3, 4). Given the severity and widespread usage of materials at the component and printed wiring board levels subject to these effects, moisture exposure mitigation is essential to any reliable SMT assembly process.

Fortunately, the moisture sensitivity issue and approaches for its avoidance are well understood. Proper drying and appropriate low humidity storage prior to solder reflow are sufficient to prevent most moisture-related damage (1). For most component types including non-hermetic surface mount devices (SMD), non-integrated circuit (IC) electrical components, etc. the classification of and parameters for appropriate handling, storage, and drying are well documented. Currently three industry standards apply to the moisture sensitivity/solder reflow issue. Firstly, IPC/JEDEC J-STD-033 specifies the proper drying conditions, storage, packaging, and exposure time ("floor life") for a wide range of components and exposure conditions by moisture sensitivity level (5). Next, IPC/JEDEC J-STD-020 contains guidance on determining the moisture sensitivity level of non-hermetic surface mount devices when exposed to eutectic Sn-Pb and Pb-free solder reflow (6). Lastly, ECA/IPC/JEDEC J-STD-075 covers the classification of process sensitivity (including moisture) /solder reflow levels for non-IC electronic components (7). For the component classes covered, these specifications provide ample information for establishing guidelines for avoiding moisture related issues during solder reflow.

Unfortunately, one component category not addressed in detail in these specifications are solderable connectors. Tables 10-1 and 11-1 from ECA/IPC/JEDEC J-STD-075 for "Through-Hole Connectors" and "SMT Connectors for through hole reflow", respectively, indicate the following: "See Supplier specific component wave solder [reflow] information and recommendations. [Process Sensitivity Level] classification to this specification is required." (6) In addition, IPC/JEDEC J-STD-033 specifically indicates in paragraphs 1.3.1 and 1.3.4 that the standard does not apply to solder immersion reflow processes like wave soldering or "Point-to-Point Soldering"…assembly processes commonly used during connecter assembly (5). This leaves the available guidance required for ensuring moisture sensitivity/solder reflow avoidance of this category of components lacking.



http://www.amphenolrf.com/919-132j-71pt.html

http://www.mouser.com/ProductDetail/TE-Connectivity/5-1634552-1/?qs=LASUwJSZkDl%252b2F3wvi51AA%3D%3D&gclid=CNzL-byP8c0CFVhahgodRIUABw

http://www.amphenolrf.com/smp-msld-pcs.html

http://www.amphenolrf.com/908-22100.html

http://www.amphenolrf.com/132134-10.html

Figure 1. Typical solderable RF connector configurations with components and solderable surfaces indicated.

A connector category of particular interest are SMT solderable (high) radio frequency (RF) connectors. While historically their use was mostly limited to aerospace and communications applications, as sensor technology expands into the industrial and automotive markets their utilization is becoming more prevalent. RF connectors are used to interface microstrip or stripline traces within a printed circuit board (PCB) to a coaxial cable. They maintain the coaxial structure consisting of a conductive metal center pin surrounded by a non-conductive dielectric material which maintains the center pin's position with respect to the exterior conductive metal connector shroud. Typical configurations of SMT solderable RF connectors are shown in Figure 1. A key aspect in their performance is matching impedance across the interface to minimize interfacial RF return loss. This often requires having dielectric material within close proximity to the solderable locations of the connector pin and shroud and also constrains material selection. The function of interfacing to a cable connector also drives the common use of Au-plating as the exterior finish for the shroud and center pin which often must be removed prior to solder assembly on the PCB to avoid deleterious Au-Sn intermetallic formation. This removal is typically accomplished either via a double tin and wick hand soldering process or solder wave immersion. Therefore any dielectric material should be compatible with these types of solder processes.

An industry survey of available surface mount RF connectors from multiple suppliers indicates that various types of dielectric materials are currently in use. Both glass and polymeric materials are used; however the interaction mechanisms affecting glass are different from polymers so it is not included in the current work. The estimated relative frequency of use for polymer types in solderable RF connector dielectric applications found are shown in Figure 2.

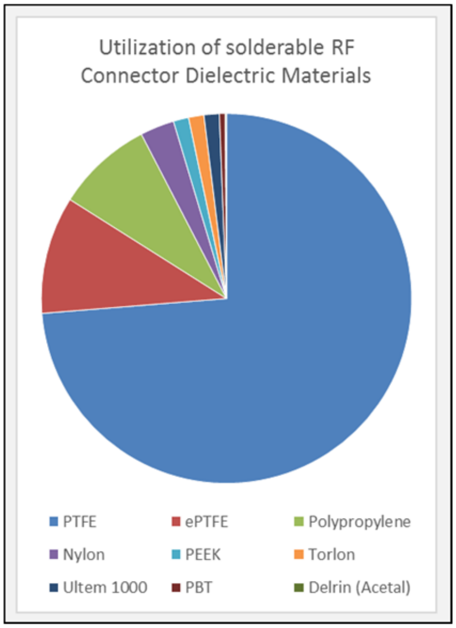


Figure 2. Estimated relative frequency of use for polymers in solderable RF connector dielectric application.

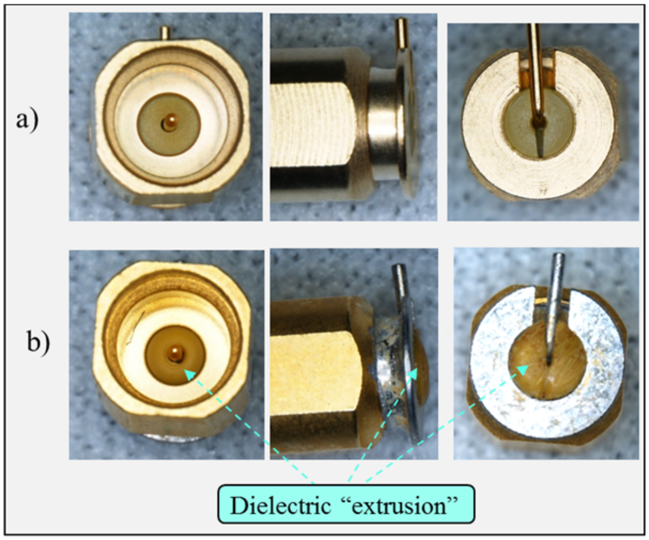


Figure 3. Examples of moisture related dielectric extrusion

in a typical solderable RF connector: a) before Au removal; b) after Au removal.

These polymers are all thermoplastics and the information available for the extent of their tendency to retain moisture varies widely (see Table 1 at end of paper). Given this distribution in hygroscopic natures, the potential for moisture related issues during solder reflow processes (including hand and wave soldering) potentially exists. Adverse moisture related issues include dielectric "extrusion" which may prevent proper installation, degrade performance and inhibit proper cable mating (see Figure 3). In addition, most of the moisture uptake versus exposure time results available are based on significantly larger sample sizes than the scale for typical RF connector dielectrics. Thus similar characterization of the moisture absorption/ desorption rates for these materials at this size scale are needed to establish proper floor life and drying times for connectors containing these materials.

The intent of the current study is to evaluate the tendencies of the identified polymeric materials currently in use as RF connector dielectrics to absorb and desorb moisture under various humidity and temperature conditions at size scales comparable to the RF connector dielectric application. Samples of various sizes were tested to ascertain if any geometric trends exist to allow for scaling of this information to a broader range of sizes than those tested. As an evaluation for screening solder process compatibility, differences in the expansion rate of these materials transitioning through soldering temperatures in a moisture saturated versus dried condition are compared utilizing thermomechanical analysis (TMA). The polymeric materials in a dried and moisture saturated state are then exposed to various soldering process conditions including convective reflow and stirred solder pot dip to qualitatively identify any potential process compatibility issues. These results are then used "to classify" the relative process and/or moisture sensitivity levels for the various polymeric materials evaluated in accordance with the available specifications.

EXPERIMENTAL PROCEDURE

Sample Geometry

Four different sample geometries were utilized in the current experiment. Disc samples were cut from ¼" and $^3/_8$" diameter raw material rods for the materials listed in Table 1 (at end of paper). Due to material availability issues, only large diameter Ultem® samples were fabricated. The samples were cut using a diamond saw, deburred and finely sanded to achieve the desired final thickness of 2±0.2 mm. A 3/16" (4.76 mm) diameter coaxial hole was drilled in a subset of samples for each size to produce samples with the desired surface area to volume ratio and similar "length" scales to match the typical hollowed cylinder geometry of the dielectric application. Nominal dimensions for the two sizes of solid and hollow sample configurations are shown below in Figure 4. Actual exterior thickness and radius measurements for each sample were measured and used to estimate their volume and surface area. All samples were cleaned using electronics grade isopropyl alcohol then baked for 135 hours @ 125+10/-0°C to achieve an initial dry state.

Absorption

The moisture absorption test consisted of exposing separate groups of three of each sample geometry per material to four different moisture/temperature exposure levels selected based on available data for the materials under test (8). The initial dried mass for each group was recorded and used for a reference for comparison with mass measurements taken at various time intervals as the materials were allowed to approach full moisture saturation at each condition.

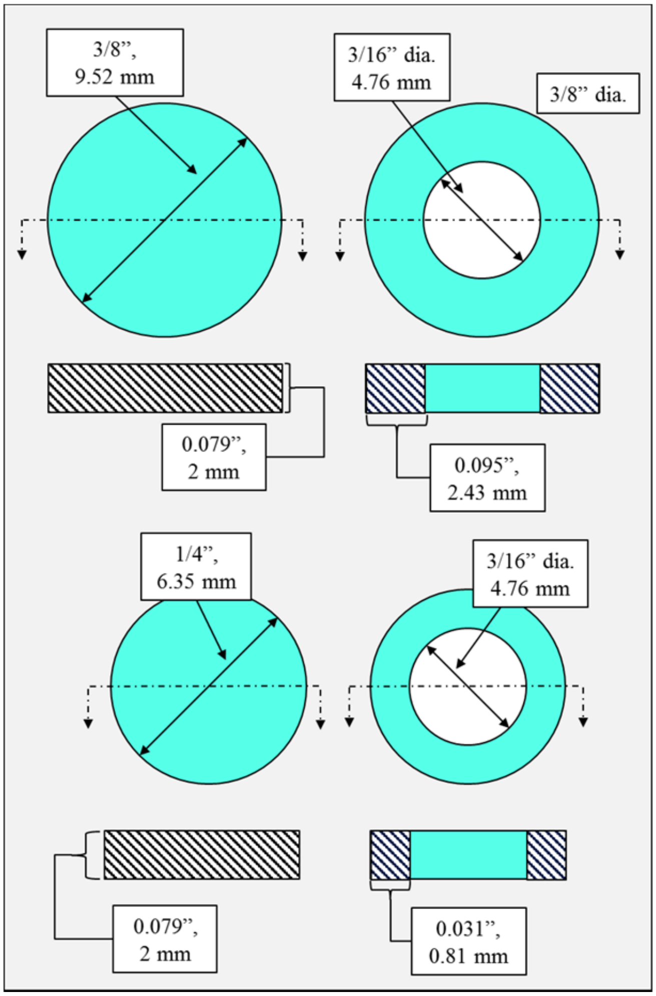


Figure 4. Sample geometry used in current experiment: large solid (LS); large hollow (LH); small solid (SS); small hollow (SH)

Mass measurements were performed using a Mettler Toledo XP405 DeltaRange mass scale with a 0.01 mg accuracy meeting the requirements of standard moisture absorption test method, ASTM D570 (9). The high humidity test was conducted in a closed 450 ml bottle filled with 50 ml of deionized (DI) water. The samples are contained within a nested glass sample holder placed inside the closed bottle preventing direct contact with the enclosed liquid. The sample-containing closed bottle is then heated in an oven to the test temperature indicated. According to thermodynamic theory for a mixture of dry air and moisture in contact with liquid water in a closed vessel, this test configuration should approach saturation condition at the test temperature or ~100%RH. The 83+%RH value indicated in Table 2 was determined by considering the pressure change of the air contained within the vessel that results during heating the closed bottle from ambient to the test temperature and is considered the minimum relative humidity value possible (10).

Table 2. Temperature/Moisture exposure conditions.

	Condition	Relative Humidity	Temp.
1	Ambient, Air	50±2%RH	20±1 °C
2	Ambient, DI water immersion	N/A	20±1 °C
3	High humidity	83+%RH	50±5 °C
4	Hot, DI water immersion	N/A	70±5 °C
5	Dry box	<10%RH	20±1 °C

Desorption

The moisture desorption test consisted of exposing a subset of the same sample groups of three of each sample geometry per material after achieving moisture saturated to a drying oven bake of 125+10/-0°C as prescribed in J-STD-033 (5). Mass measurements were collected at various time intervals until a dried state was achieved.

Expansion Stability Evaluation

The effect of moisture on the expansion rate versus temperature was evaluated using thermal mechanical analysis (TMA). Measurements were made using a TA Instruments Q400 TMA system which measured the linear dimension change of the sample over temperature. Samples are held between a stationary stage and mobile probe with an applied force of 0.05 N to maintain contact with the sample over temperature. One dry and one moisture saturated LH sample was subjected to up to 2 temperature cycles from ambient up to 275°C with a ramp rate of 180°C/min and a 0.2 minute (~10 sec) dwell time at hot as described in the classification for wave soldering approach described in J-STD-075 (7). Only one thermal cycle was performed on materials exhibiting excessive deformation. Differences in their expansion behavior were assessed and the results compared with actual solder compatibility test results to ascertain whether TMA screening is an effective analytical method for evaluating solder process sensitivities.

Solder Process Compatibility

Utilizing J-STD-020 and -075 as a guide, the process and moisture sensitivities for reflow and wave solder conditions were evaluated (6, 7). Before and after comparative visual inspection was used to determine any physical changes that occurred to the polymeric material samples when exposed to the different solder reflow conditions. Differences in the results for dry and moisture-saturated samples were used to identify any moisture related sensitivities. The convective reflow exposure was performed using a Vitronics Soltec XPM-730 multi-zone reflow oven. The thermal profile had a target peak temperature of 260°C with a maximum ramp-up rate of 3°C/s. These exposure conditions are similar to the Pb-free solder classification profile from J-STD-020 with slightly warmer soak temperature (215°C) and shorter time over liquidus (40-120 seconds) (5). Each sample group which included one of each sample size were contained within a shallow aluminum cup attached to the top surface of a sheet of PCB substrate during the exposure. The stirred solder pot test was performed in a 275°C solder pot containing eutectic Sn-Pb solder seeking to simulate the wave solder conditions from J-STD-075 (7). Large hollow samples were dipped in a 25% solids RMA (ROL0) flux prior to immersion. The samples, held using tweezers, were submerged into the liquid solder bath and continuously stirred during the 10 second exposure. Samples shown to have melted at the solder pot temperature during TMA tests were limited to a 5 second exposure.

RESULTS AND DISCUSSION

Absorption

A comparison of the absorption results for the materials under evaluation are shown in Figures 5a-5d which present the % mass change due to moisture uptake over time for the different temperature/humidity exposures performed. The %mass change is calculated between the instantaneous mass, M_t, and the initial dry reference mass, M_{REF}, using Equation 1.

$$\%Mass\ Change = \frac{M_t - M_{REF}}{M_{REF}} * 100\% \qquad 1$$

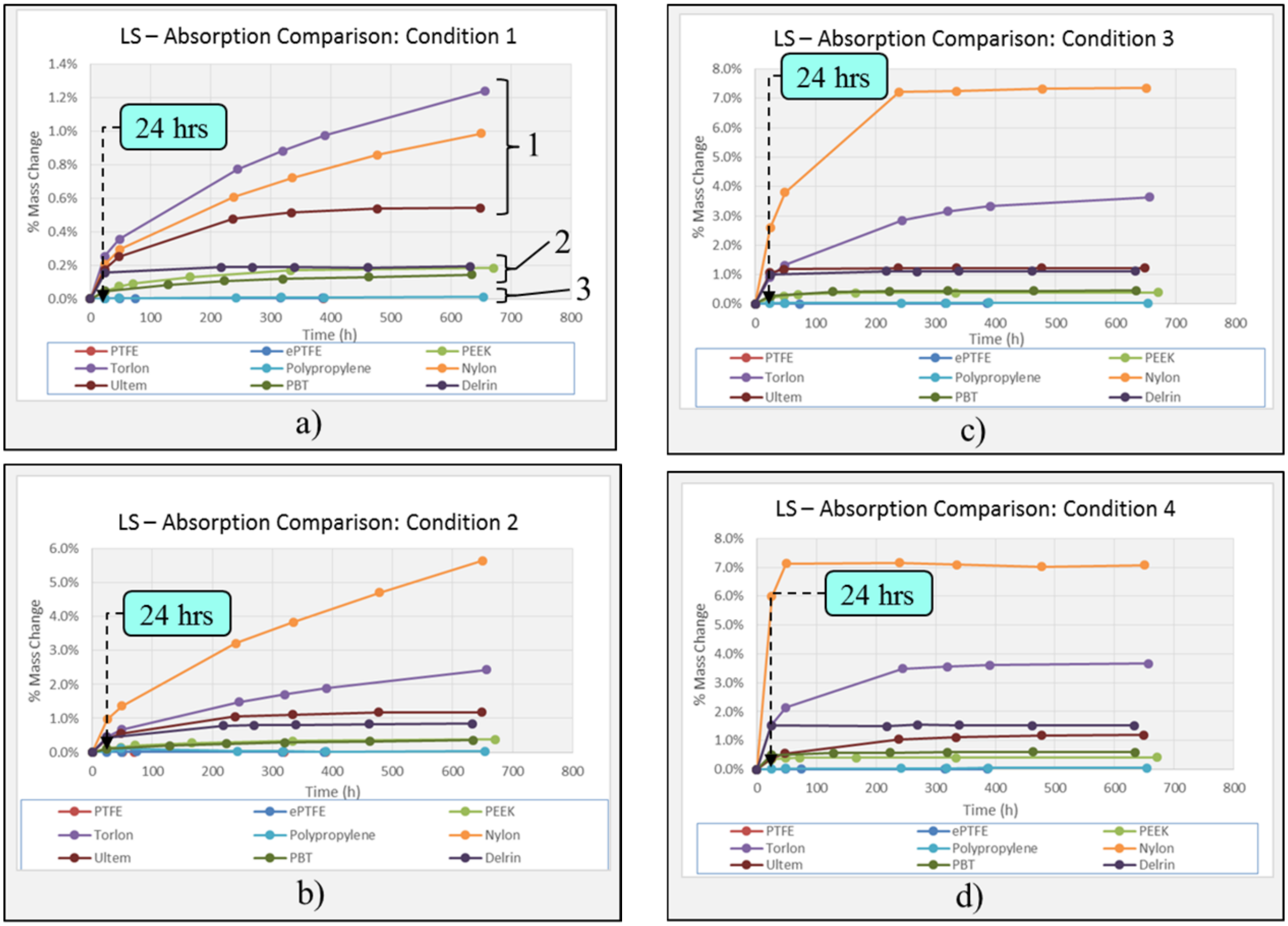
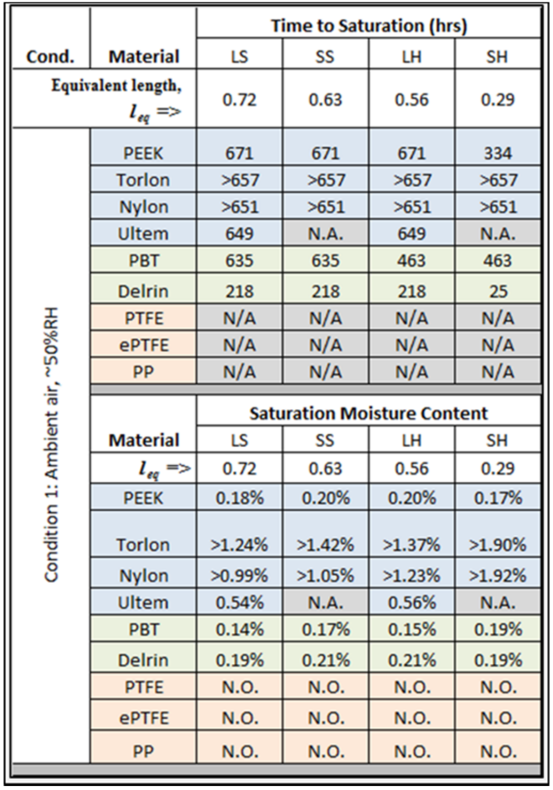


Figure 5. Moisture absorption versus time for thermoplastic polymers used in RF dielectric applications exposed to different temperature/humidity conditions: a) Condition 1; b) Condition 2; c) Condition 3; and d) Condition 4 – sample group LS shown.

For those materials exhibiting moisture absorption, the initial rapid rate of uptake slows with increasing time of exposure until an equilibrium or saturated state is reached consistent with the mass diffusion processes at work. The exposure duration and % mass change at saturation varied depending on the temperature/humidity exposure environment. For PTFE, ePTFE and polypropylene (PP), all exposure conditions failed to produce a significant mass change, matching the results for the control sample groups. During the ~600+ hour test duration in each of the 4 environments, all absorptive materials show signs of achieving near saturation except for Nylon (polyamide 6,6) and Torlon® under ambient temperature conditions which have yet to reach their equilibrium state. The results for the ambient temperature, ~50%RH conditions most applicable to floor life are provided in Table 3.

The extent of absorptivity for these materials appear to fall into three categories based on the %mass change resulting from saturation: 1) *highly absorptive (>0.5% increase)* – polyamide 6,6 (nylon), polyamide–imide (Torlon®), polyetherimide (Ultem®), and acetal resin (Delrin®); 2) *slightly absorptive (0.1-0.5% increase)* – polyetheretherketone (PEEK); polybutylene terephthalate (PBT); and 3) *non-absorptive* (<<0.1% increase) – Polytetrafluoroethylene (PTFE), expanded PTFE, and polypropylene (PP). The materials with the highest saturation moisture uptake for the samples measured from greatest to least are: Nylon; Torlon®; Ultem® and Delrin®; PBT and PEEK; and PP, ePTFE and PTFE.

Table 3. Saturation times and Saturation %mass changes for RF Dielectric materials exposed to Condition 1. N.A. – not available; N/A – not applicable; N.O. - not observed.



Cond.	Material	Time to Saturation (hrs)			
		LS	SS	LH	SH
Equivalent length, l_{eq} =>		0.72	0.63	0.56	0.29
Condition 1: Ambient air, ~50%RH	PEEK	671	671	671	334
	Torlon	>657	>657	>657	>657
	Nylon	>651	>651	>651	>651
	Ultem	649	N.A.	649	N.A.
	PBT	635	635	463	463
	Delrin	218	218	218	25
	PTFE	N/A	N/A	N/A	N/A
	ePTFE	N/A	N/A	N/A	N/A
	PP	N/A	N/A	N/A	N/A
		Saturation Moisture Content			
	Material	LS	SS	LH	SH
	l_{eq} =>	0.72	0.63	0.56	0.29
	PEEK	0.18%	0.20%	0.20%	0.17%
	Torlon	>1.24%	>1.42%	>1.37%	>1.90%
	Nylon	>0.99%	>1.05%	>1.23%	>1.92%
	Ultem	0.54%	N.A.	0.56%	N.A.
	PBT	0.14%	0.17%	0.15%	0.19%
	Delrin	0.19%	0.21%	0.21%	0.19%
	PTFE	N.O.	N.O.	N.O.	N.O.
	ePTFE	N.O.	N.O.	N.O.	N.O.
	PP	N.O.	N.O.	N.O.	N.O.

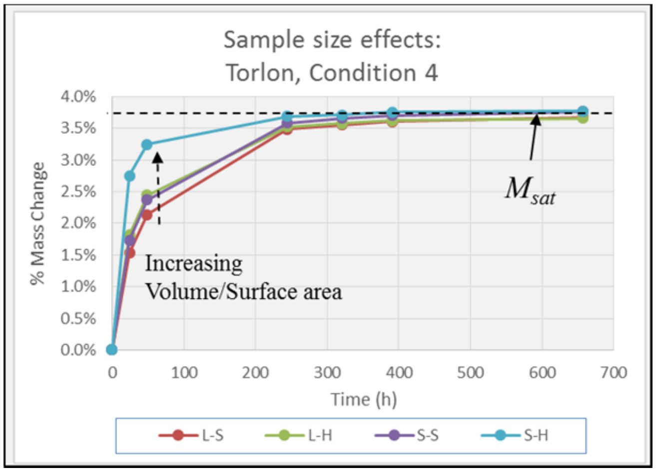


Figure 6. Comparison of moisture uptake (mass change) versus time for different sample geometries.

Comparison of the results from the current study with available published moisture absorption results exposed to similar conditions reveals significantly higher moisture uptake for all the absorptive material categories (see Table 1 at end of paper). This difference can be attributed (at least partially) to the sample size effects discussed previously. Figure 6 shows the typical difference caused by sample size on the relative moisture uptake for a given absorptive material type with smaller sample groups increasing in rate to a similar saturated state faster than larger ones.

In traditional moisture absorption studies, the analysis of diffusion properties uses the relationship between the ratio of M_t and saturated mass, M_{sat}, versus the ratio of the square root of time, *t*, and diffusion length, *l*, to determine diffusion behavior (11). The sample configuration used are thin with respect to their area in order to limit the moisture gradient to a single dimension simplifying the analysis. In the current experiment where cylindrical (solid and hollow) samples are used, the moisture concentration gradient exists in three dimensions. Therefore acquisition of the diffusion characterization applying the classical approach requires a far more complex multidimensional analysis. However, comparison of the % mass change results for the different sample sizes at each exposure time for a given exposure condition in Figure 6 suggests the existence of a relationship between the sizes tested that may allow for simplification. Fortunately that simplification is achieved when the ratio of the sample's volume, *V*, to surface area, *SA*, is substituted as an equivalent length, l_{eq}. As Figure 7 shows, plotting these results produces the same convergence typical for one-dimensional, Fickian diffusion allowing for estimation of the mass diffusion coefficient values, *D*, for each material and exposure condition (11).

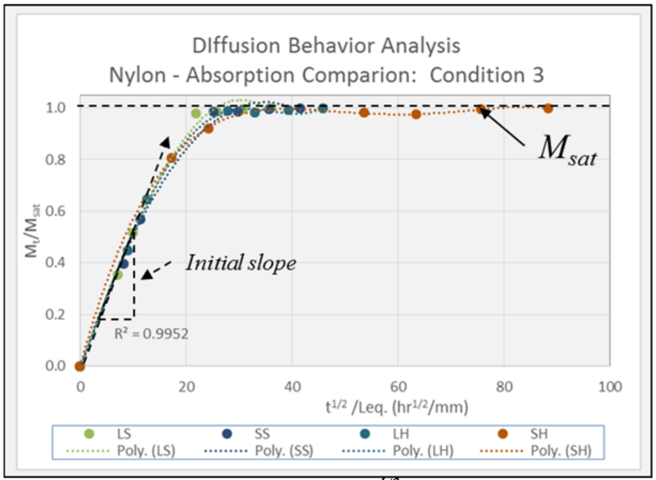


Figure 7. Typical M_t/M_{sat} versus $t^{1/2}/l_{eq}$ for different sample geometries.

The value of *D*, when constant, is estimated from the initial slope value using the relationship shown in Equation 2 (11). These results, provided in Table 4, are used to estimate the time to moisture saturation for sample geometries of various sizes to determine their expected time to saturation under similar exposure environments. Furthermore, the diffusion coefficients for the high humidity/immersion tests (Conditions 2-4) exhibit an exponential relationship with temperature (see Equation 3) providing additional confirmation of Fickian behavior for these polymers (11). Here the temperature dependent diffusion coefficient, *D(T)*, is related to an initial value, D_o; and exponentially with the ratio of its activation energy, ΔE, Boltzmann's constant, *k*, and the absolute temperature, *T*.

$$\frac{M_t}{M_{sat}} = 4\left(\frac{Dt}{\pi l_{eq}^2}\right)^{1/2} \qquad 2$$

$$D(T) = D_o exp\left(-\frac{\Delta E}{kT}\right) \qquad 3$$

Table 4. Calculated diffusion coefficients for absorptive materials tested per exposure environment.

Material	Diffusion Coefficient, *D* (mm^2/s)			
	Condition 1	Condition 2	Condition 3	Condition 4
PEEK	6.15E-08	8.87E-08	3.48E-07	6.99E-07
Torlon	1.87E-08	1.83E-08	7.54E-08	1.53E-07
Nylon	1.08E-08	3.34E-08	1.46E-07	8.09E-07
Ultem	1.14E-07	1.31E-07	7.16E-07	2.41E-06
PBT	8.93E-08	7.78E-08	4.36E-07	6.87E-07
Delrin	8.93E-08	7.78E-08	4.36E-07	6.87E-07

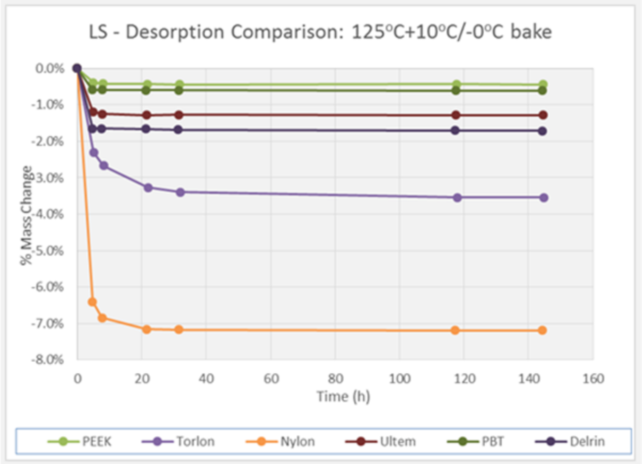


Figure 8. Moisture desorption versus time for thermoplastic polymers used in RF dielectric applications – sample LH.

Desorption

A comparison of the %mass change versus bake time is provided in Figure 8. In this case, the M_{REF} value used to calculate the % mass change from Equation 1 is the mass of a sample group at moisture saturation. Saturated samples exposed to Condition 4 were used for this testing. As Figure 8 indicates, the desorption, or drying, occurs in the same fashion as that observed for the absorption, with the rate of mass change decreasing rapidly until an equilibrium dry state is reached. The rapid rate of decrease when compared to absorption is due to the diffusion process's exponential increase with increased temperature (see Equation 3). The required drying time for each material for the 125°C+10°C/0°C bake condition are shown in Table 5.

Table 5. Drying times for absorptive polymers used in RF connector dielectric applications.

Material	Time to dry (hrs)			
	LS	SS	LH	SH
l_{eq} =>	0.72	0.62	0.55	0.30
PBT	5	5	5	5
Delrin	5	5	5	5
PEEK	8	8	8	5
Ultem	8	N/A	8	N/A
Nylon	21	21	21	5
Torlon	40	40	32	21

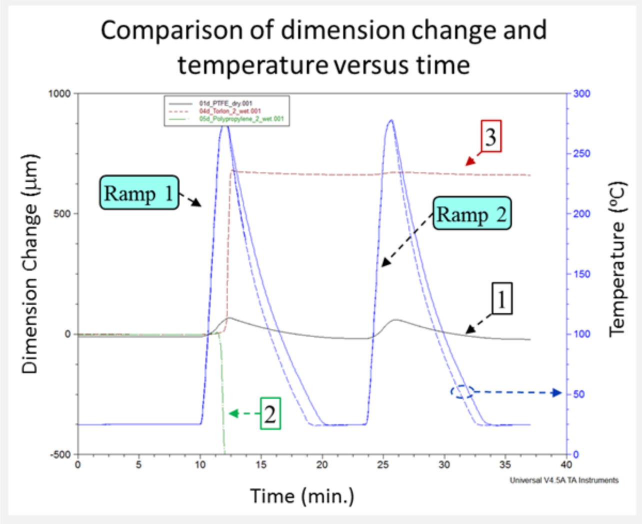


Figure 9. Three types of TMA dimension change responses exposed to simulated wave solder temperature profile: 1) normal; 2) excessive softening; and 3) expansion.

Expansion Stability Evaluation

Three different expansion responses were observed during TMA testing. Figure 9 shows plots of the dimensional change and temperature versus time for those different responses. *Response 1, normal,* is the response for a material unaffected by moisture where the dimension change is primarily due to thermal expansion and is fully recoverable as the change disappears when the sample returns to its reference temperature. *Response 2, excessive softening,* occurs when the sample material melts or reaches a temperature above its glass transition where it can no longer withstand the compressive probe force. *Response 3, expansion,* occurs when the material blisters due to trapped moisture resulting in an irreversible dimensional increase. Figure 10 shows examples of the visual changes which occurred in the tested materials undergoing these different responses. A summary of the types of response for each material for both dry and wet conditions are included in Table 6 (at end of paper). In general, only highly absorptive materials exhibited differences between their moisture saturated and dry states. For nylon, Torlon®, and Ultem® blistering was widespread in the wet samples while the dry samples responded normally. Delrin®'s softened excessively which likely allowed any internal moisture to escape without forming permanent blisters. There was no correlation between moisture absorptive categories for materials in the excessive softening response with at least one material coming from each group.

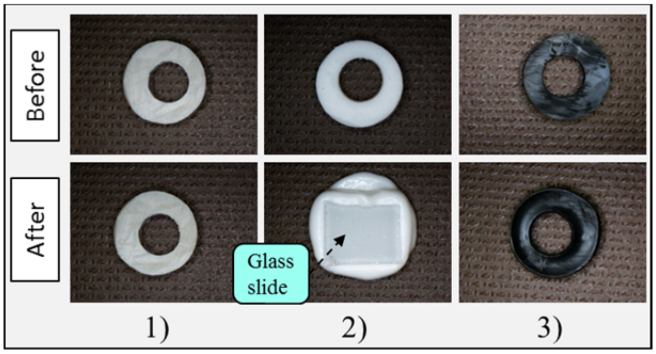


Figure 10. Before and after pictures of material samples for each dimension change response type after TMA: 1) normal; 2) excessive softening; and 3) expansion.

Solder Process Compatibility

The material responses for the two solder reflow process sensitivity exposures were similar to those for the Expansion Stability Evaluation discussed in the previous section. During convective reflow and solder pot immersion, significant blistering occurred in moisture saturated, highly-absorptive material samples and excessive softening materials approached a liquid state. There did not appear to be any observable difference due to the sample size during the convective reflow test, suggesting that the size differences did not produce a significant temperature difference between them. The physical changes observed for each material category are show in Figures 11 and 12 for stirred solder pot and convective reflow respectively. A summary of these results for each material are included in Table 6 (at end of paper).

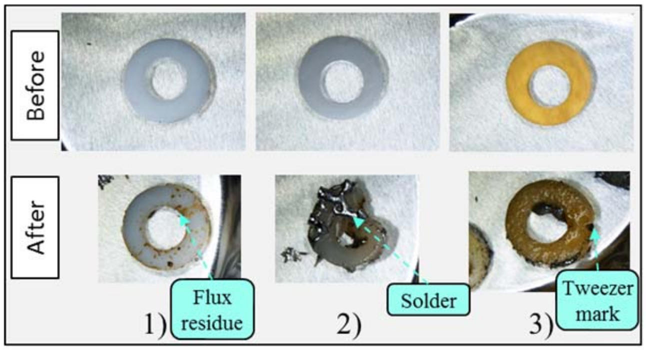


Figure 11. Before and after pictures of material samples for each dimension change response type after stirred solder pot exposure: 1) normal; 2) excessive softening; and 3) expansion.

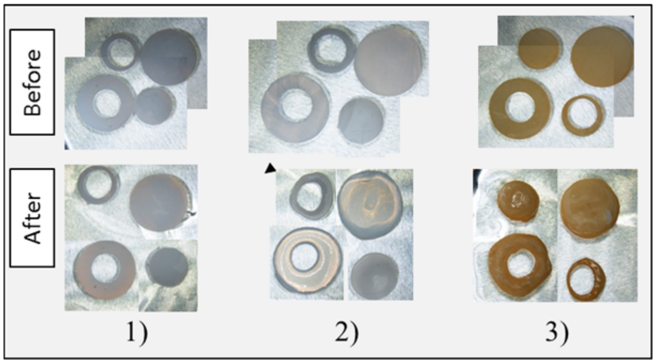


Figure 12. Before and after pictures of material samples for each dimension change response type after convective reflow exposure: 1) normal; 2) excessive softening; and 3) expansion.

Sensitivity Classification

Based on the results of the above described experiments, process and moisture sensitivity levels are estimated for RF connectors containing the evaluated raw materials as dielectrics. The Floor Life estimates for each are arbitrarily taken as the time for the materials to reach ~25% moisture saturation when exposed to Condition 1. Moisture sensitivity classification leverages those specified for surface mount devices in Table 5-1 of J-STD-033 (5). In the process sensitivity evaluations for excessive softening materials, the classification temperature, T_c, was selected based on the highest of 90% of their melting temperature or the maximum safe test temperature observed and should be considered as a maximum safe processing temperature limit. Classifications for wave soldering and reflow soldering are based respectively on Tables 5-1 and 5-2 of J-STD-075 (7). The classification results for each material are provided in Table 6 (at end of paper). Based on these classifications, the storage and handling guidelines within J-STD-033 for the particular moisture sensitivity class should be applied (5).

CONCLUSIONS

Moisture effects on the polymeric materials used in solderable RF connector dielectrics have been studied. For the thermoplastic materials evaluated, the moisture absorption and desorption processes occur via Fickian diffusion. The time to saturated state depended on the material type, exposure condition and size of sample whereas the saturated % mass change depended on material type and exposure condition. Analysis of these materials in cylindrical geometries (solid and hollow) typical of connector dielectrics (within the size range evaluated) is simplified by using the ratio of their volume to surface area as an effective length in determining diffusion coefficients. The polymers evaluated fall into three categories of absorptive saturation behavior: *highly absorptive*; *slightly absorptive*; and *non-absorptive*. Exposure to soldering processes yielded two types of deleterious responses in the materials tested. Highly absorptive materials in a saturated state exhibit severe blistering while excessive softening materials deformed significantly when exposed to the soldering temperatures independent of moisture saturation state. Since these conditions would adversely affect the connector performance and reliability in their end use application, the solder reflow/moisture sensitivity classification of these materials was performed. Finally, TMA results correlated well with solder reflow exposures indicating that it is an effective analytical method for characterizing solder process sensitivities.

FUTURE WORK

Future work will include continuation of the ambient absorption experiments to ensure that the saturation states have been attained for all materials evaluated. In addition, experiments confirming the damage threshold of 25% moisture saturation will be performed.

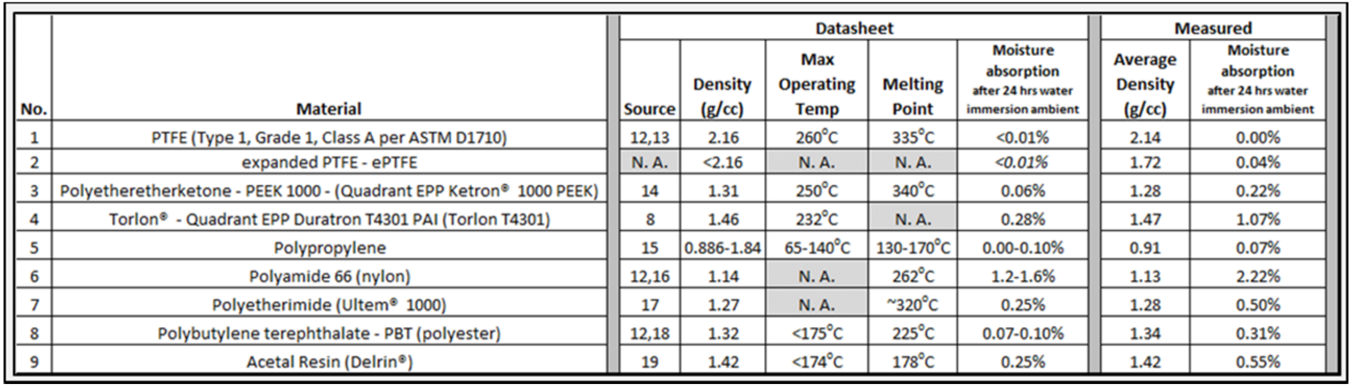
ACKNOWLEDGEMENTS

The author would like to acknowledge Harris Corporation's Specialty Engineering and Advanced Operations Technology (AOT) departments for their support of this effort, in particular, Carlyn Smith, PhD (for paper review and technical discussions); Phill Nickel (for manufacturing support); Tony LaManna (AOT), Stewart Weimer, Frank Fieldson, and Anne Ramsey.

REFERENCES

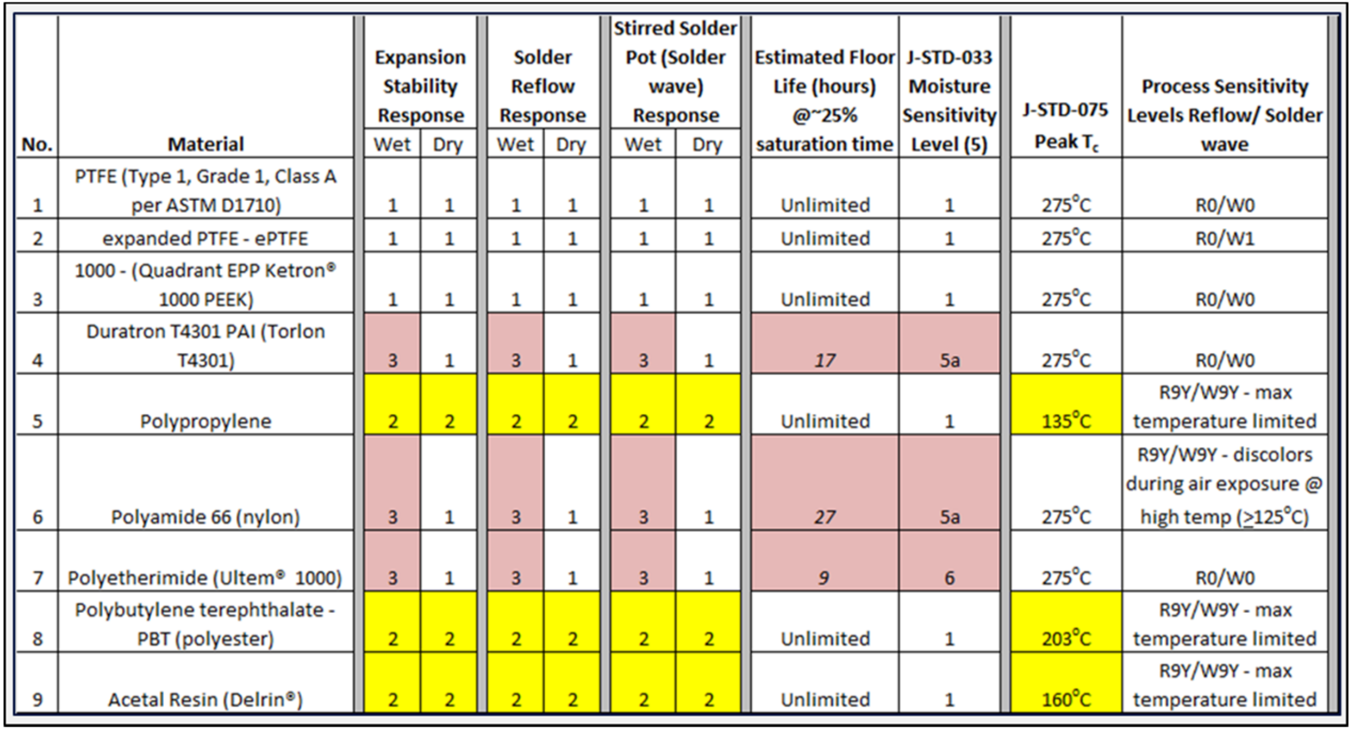
1. Gallo, A. A., Munamarty, R., Popcorning: A Failure Mechanism in Plastic-Encapsulated Microcircuits, *IEEE Transactions on Reliability*, Vol. 44, No. 3, September, 1995, pp. 362-367.
2. Baschek, G., Hartwig, G., Zahradnik, F., Effect of water absorption in polymers at low and high temperatures, *Polymer*, Vol. 40, No. 12, June 1999, pp. 3433-3441.
3. He, Y., Fan, X., In-situ Characterization of Moisture Absorption and Desorption in a thin BT Core Substrate, *2007 Proceedings 57th Electronics Components and Technology Conference,* Reno, NV., May 29, 2007 – June 1, 2007, IEEE, pp. 1375-1383.
4. Sood, B., Pecht, M., Controlling Moisture in Printed Circuit Boards, *Proceedings IPC APEX EXPO Technical Conference,* Las Vegas, NV., April 12-14, pp. 1.
5. IPC/JEDEC J-STD-033C-1, August 2014
6. IPC/JEDEC J-STD-020E, January 2015
7. ECA/IPC/JEDEC J-STD-075, August 2008
8. *TORLON Polyamide-imide Design Guide*, Solvay Advanced Polymers, 2003.
9. ASTM D570-98
10. Moran, M. J., Shapiro, H. N., *Fundamentals of Engineering Thermodynamics*, John Wiley & Sons, New York, NY, 1988, pp. 572-580.
11. Shirangi, M. H., Michel, B., Chapter 2: Mechanism of Moisture Diffusion, Hygroscopic Swelling, and Adhesion Degradation in Epoxy Molding Compounds, *Moisture Sensitivity of Plastic Packaging of IC Devices*, Fan, X., Suhir, E. Editors., Springer, NY, 2010, pp. 29 – 66.
12. McMaster Carr *More About Plastics*, 2016, http://www.mcmaster.com/#=13jdo9p
13. Aetna Plastics Corp., DuPont Teflon® PTFE Specification, 2016
14. Quadrant Engineering Plastic Products, Ketron PEEK-1000 datasheet, 2003
15. MATWEB datasheet for Polypropylene, Extrusion Grade
16. Dupont Zytel® 101 NC010 Datasheet, 2014.
17. Sabic Ultem® Resin 1000 datasheet, 2016
18. Dupont Crastin® 6129 NC010 Thermoplastic Polyester Resin datasheet, 2014.
19. Dupont Delrin® Acetal Resin Design Information, 02.03

Table 1. Polymeric materials used in solderable RF connector dielectric applications. N.A – not available



		Datasheet					Measured	
No.	Material	Source	Density (g/cc)	Max Operating Temp	Melting Point	Moisture absorption after 24 hrs water immersion ambient	Average Density (g/cc)	Moisture absorption after 24 hrs water immersion ambient
1	PTFE (Type 1, Grade 1, Class A per ASTM D1710)	12,13	2.16	260°C	335°C	<0.01%	2.14	0.00%
2	expanded PTFE - ePTFE	N. A.	<2.16	N. A.	N. A.	*<0.01%*	1.72	0.04%
3	Polyetheretherketone - PEEK 1000 - (Quadrant EPP Ketron® 1000 PEEK)	14	1.31	250°C	340°C	0.06%	1.28	0.22%
4	Torlon® - Quadrant EPP Duratron T4301 PAI (Torlon T4301)	8	1.46	232°C	N. A.	0.28%	1.47	1.07%
5	Polypropylene	15	0.886-1.84	65-140°C	130-170°C	0.00-0.10%	0.91	0.07%
6	Polyamide 66 (nylon)	12,16	1.14	N. A.	262°C	1.2-1.6%	1.13	2.22%
7	Polyetherimide (Ultem® 1000)	17	1.27	N. A.	~320°C	0.25%	1.28	0.50%
8	Polybutylene terephthalate - PBT (polyester)	12,18	1.32	<175°C	225°C	0.07-0.10%	1.34	0.31%
9	Acetal Resin (Delrin®)	19	1.42	<174°C	178°C	0.25%	1.42	0.55%

Table 6. Process and Moisture Sensitivity Classification of polymeric materials used in solderable RF connector dielectrics. Response 1 = normal; Response 2 = excessive softening; Response 3 = expansion



No.	Material	Expansion Stability Response		Solder Reflow Response		Stirred Solder Pot (Solder wave) Response		Estimated Floor Life (hours) @~25% saturation time	J-STD-033 Moisture Sensitivity Level (5)	J-STD-075 Peak T_c	Process Sensitivity Levels Reflow/ Solder wave
		Wet	Dry	Wet	Dry	Wet	Dry				
1	PTFE (Type 1, Grade 1, Class A per ASTM D1710)	1	1	1	1	1	1	Unlimited	1	275°C	R0/W0
2	expanded PTFE - ePTFE	1	1	1	1	1	1	Unlimited	1	275°C	R0/W1
3	1000 - (Quadrant EPP Ketron® 1000 PEEK)	1	1	1	1	1	1	Unlimited	1	275°C	R0/W0
4	Duratron T4301 PAI (Torlon T4301)	3	1	3	1	3	1	*17*	5a	275°C	R0/W0
5	Polypropylene	2	2	2	2	2	2	Unlimited	1	135°C	R9Y/W9Y - max temperature limited
6	Polyamide 66 (nylon)	3	1	3	1	3	1	*27*	5a	275°C	R9Y/W9Y - discolors during air exposure @ high temp (≥125°C)
7	Polyetherimide (Ultem® 1000)	3	1	3	1	3	1	*9*	6	275°C	R0/W0
8	Polybutylene terephthalate - PBT (polyester)	2	2	2	2	2	2	Unlimited	1	203°C	R9Y/W9Y - max temperature limited
9	Acetal Resin (Delrin®)	2	2	2	2	2	2	Unlimited	1	160°C	R9Y/W9Y - max temperature limited