Celazole® PBI U-60
Moisture Management Guide

PBI and Moisture – An Overview

Polybenzimidazole (PBI) is a linear amorphous polymer, which in an unconstrained wet or humid environment will sorb but not react with water (Table 1).

Table 1

Water Absorption – ASTM D-570 (2" disk x 1/8")	Celazole® PBI U-60
24 hr immersion (73F)	0.4%

In the moist environment, water will move into the unconstrained polymer matrix between polymer chains, spreading them and stretching the dimensions of the shape or part. Water does not bond or react with PBI but will move freely in and out of an unconstrained matrix. In contrast, if PBI is constrained, the polymer chains will not spread and the water will not penetrate. Absorbed water can be desorbed by changing PBI to a dry environment, wherein the matrix returns to the original size and condition.

The effect of water absorption for PBI is the same as for other thermoplastics; the physical manifestation is threefold: it will change part dimensions, it can exacerbate the effects of thermal and pressure shock, and it will reduce mechanical strength.

Additionally, sorbed moisture will impact electrical insulation resistance and dielectric properties. In many situations, these undesired effects can be eliminated or mitigated if properly managed. This guide is designed for that purpose.

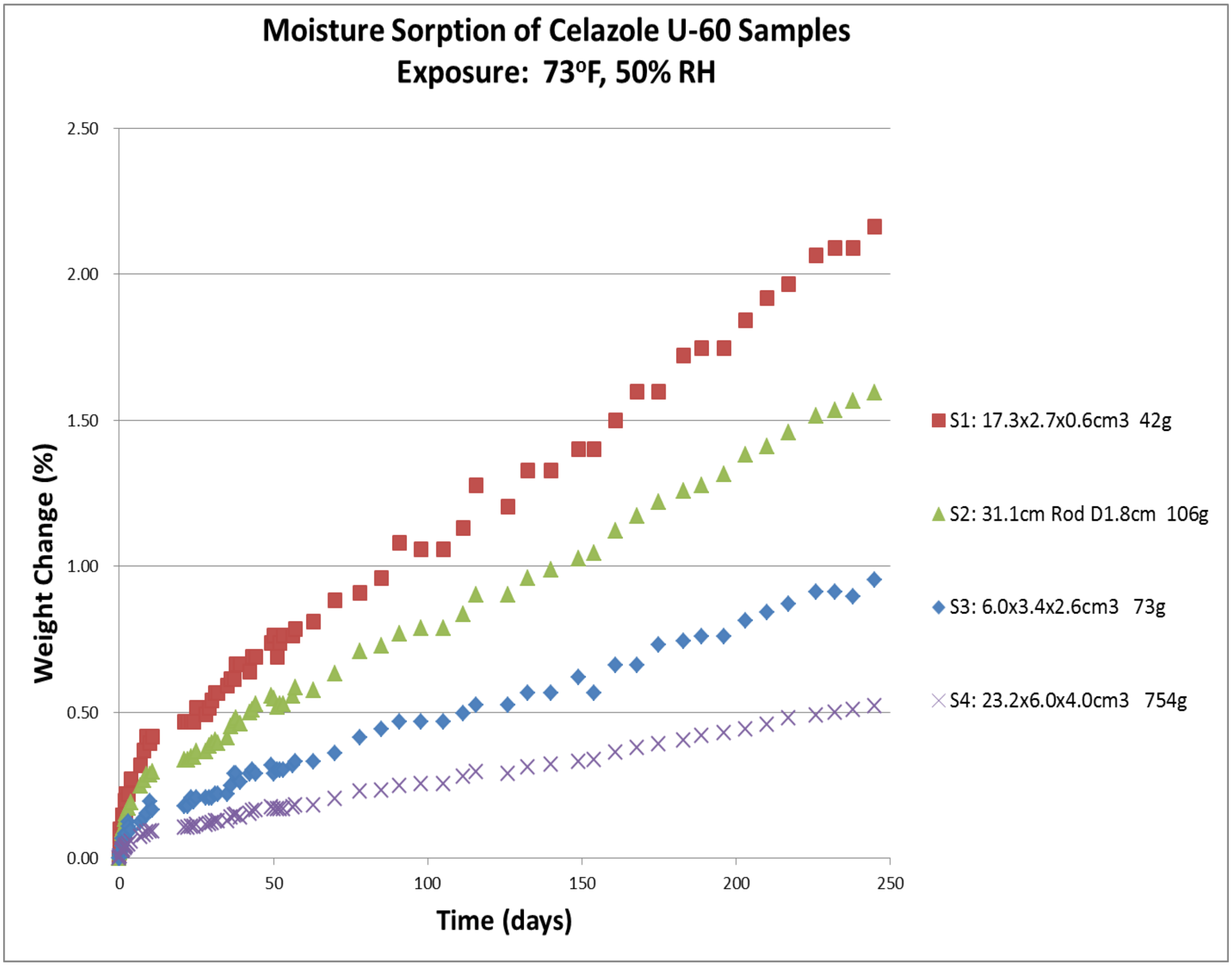
PBI and Moisture Absorption – The Fundamentals

PBI sorbs water in direct proportion to the prevailing water partial pressure, i.e. percent Relative Humidity (% R.H.) and its equilibrium saturation level varies with % R.H. obeying Henry's Law. At 30% R.H. equilibrium saturation is about 4.5%; at 50% R.H. it's about 7%. At 80% R.H. and above, the maximum equilibrium saturation of 11.7% is reached. Sorption capacity is not affected by temperature except to the extent that it affects the % R.H.

The rate of water sorption is limited by the rate of water diffusion into the PBI part. Fickian diffusion is observed as the rate of diffusion is driven by the water concentration gradient in the polymer. This rate of diffusion is a linear function of the square root of exposure time and is determined by temperature, % R.H. and part geometry. Since the rate is a function of the square root of exposure time, the rate of absorption starts out fast and slows with time. Geometry affects the rate of water sorption as the diffusion distance changes. Diffusion is dominant through exposed large planar surfaces and is minimal through exposed edges. It naturally follows then, that equilibrium concentration is achieved more readily with exposure of films and thin-walled shapes versus bulky three-dimensional shapes – all else equal.

An illustration of PBI's water absorption trend for four Celazole PBI U-60 samples is shown in Figure 1. In this example, four dried samples (S1 – S4) of Celazole U-60 were simultaneously exposed to conditioned air at 50% R.H., 73F for 250 days. Noteworthy is the difference in the rate of absorption for the various geometries.

Figure 1



The Effects of Water in PBI

An unconstrained PBI specimen exposed to a humid or wet environment will sorb water (constrained, it will not). In many cases, the effect of sorbed moisture is very small and goes un-noticed with use; however, there are situations where it's a factor that must be considered. Users should be aware of three ways in which moisture can have detrimental effects on PBI parts' physical performance: dimensional changes, cracking/blistering and strength loss.

Dimensional Changes

One effect of sorbed moisture in PBI is a temporary change in part dimensions. It is temporary to the extent that the condition is reversible when the PBI is dried. Table 2 illustrates the effect of sorbed moisture on part dimensions. As part geometries vary widely, this table should be used as a guideline only.
Also note that if a shape has not reached moisture equilibrium with its environment, there will be a moisture gradient in the part attributable to the slow moisture diffusion, wherein the surface could be moister or dryer than the core. It is equally possible for moisture concentration to be anisotropic, resulting from moisture exposure to one side of the part. Machining of a part from a stock shape in such condition could lead to warping or thickness variation. Therefore, be sure to properly dry the shape as described later in this document prior to machining.

Table 2

Dimensional Change of U-60 PBI Disk w/ Sorbed Water				
% Water Absorption	1/8"T x 2.5" Diam. Disk		3/8"T x 2.5" Diam. Disk	
	% change Thickness	% change Diameter	% change Thickness	% change Diameter
0	0	0	0	0
0.25	~0	~0	~0	~0
0.5	0.05	0.02	~0	0.02
1	0.15	0.05	0.1	0.05
2	0.6	0.1	0.7	0.15
3	1.2	0.2	1.3	0.35
4	1.9	0.3	1.5	0.45

Cracking or Blistering

While it is not common, serious part damage can result from severe environmental shocks when PBI parts have sorbed moisture. This may occur when a moisture-containing PBI part experiences a rapid and extreme change in temperature and/or pressure. For example, a part containing 4% moisture at ambient temperature and pressure which is then placed in full vacuum at 300C may crack or blister as the moisture escapes. Likewise, a PBI part saturated in steam and then rapidly decompressed may crack or blister. To avoid these situations, users must understand how to store and dry PBI parts and should refer to the guidelines herein.

Strength Loss

Finally, water absorption will affect strength. In the extreme case, PBI can lose up to 45% of its strength when fully saturated with water/steam. Tables 3 and 4 illustrate this point. Conversely, a part saturated with water and then dried will see strength, modulus, elongation and hardness restored to original values (Table 4).

Table 3

PBI U-60 Strength Change after Steam Exposure (650F, 2200 psi)		
	Tensile Strength (kpsi)	Hardness Shore D
Baseline	23	95
Steam 1 day	13	93
Steam 7 days	12	91

Table 4

PBI U-60 Strength Change after Boiling in Water							
	Tensile Strength (kpsi)	Elongation (%)	Tensile Modulus (kpsi)	Compressive Strength @ 10% Strain (kpsi)	Compressive Modulus (kpsi)	Hardness Rockwell K	Hardness Shore D
Baseline	22	2.4	840	56	860	115	99
Boiling 1 day	18	2.6	780			90	
7 days	17	2.9	720			60	95
30 days	14	2.6	680	32	610	55	93
Boiling 7 days; dried	24	3.2	860			104	97

Controlling Moisture in PBI Parts

For predictable machined part fit and performance, stock shapes and finished parts should be stored in a dry environment. Both stock shapes and finished parts should be packed in moisture barrier packaging. Open packaging just prior to use. In the event that a part may have adsorbed so much moisture as to risk shocking it when placing it in high temperature or vacuum service, consider drying the material prior to use or re-use.

Celazole parts are dried by putting them in a low Relative Humidity environment. For quick and safe drying, dry the parts in a vacuum oven at 150C. Alternately, where vacuum is not available, one can use dry heat at 200C. For best practice, always place the part in oven at ambient temperature and ramp oven heating and cooling as prescribed below. See Table 5 below for complete drying instructions.

Table 5

Drying Cycle and Ramp Rates
1. Take part from room temperature to 130C, at rate of 50 C/hr. 2. Hold temperature at 130C for 1~2 hrs. 3. Increase temperature from 130C to 200C, at rate of 25 C/hr. If vacuum is used, stop at 150C. 4. Hold at 200C (150C with vacuum) for 4 to 72 hours depending upon part size, original moisture content and application temperature and pressure. In general, 4 hour hold time is sufficient for most parts used below 300C For large parts, parts with high moisture content, and application environments with rapid heating above 400C one should consider a 72 hour hold cycle. 5. Cool from 200C (150C with vacuum) to 130C at rate of 10C/hr. 6. Turn dryer off when temperature reaches 130C. Allow to slowly cool until safe to package.

Packaging Materials

Manufacturers of laminated packing films offer a variety of products that serve as excellent moisture barriers for PBI with high tear and burst strengths (Table 6). The best moisture barriers and most cost effective packing films are the aluminized laminates of oriented polypropylene and polyethylene, or in extra heavy duty construction – aluminized laminates of nylon, polyethylene and ethylene-vinyl alcohol copolymer (EVOH). These opaque heat sealable laminates are available in durable puncture resistant constructions. If transparency is not important, these aluminized laminates are the best choice as they have the lowest water vapor transmission rate, are very durable, and cost less than high performing transparent films.

If package transparency is important, be sure to check the film's specification for water vapor transmission. Biaxially oriented films are more effective than monoaxial films as barriers to water vapor transmission and are also very tough and resistant to tears. Transparent films with very low water vapor transmission rates include (in order of preference) PCTFE, Polyvinylidene chloride (Saran), PTFE, and HDPE. Most heat sealable films contain a polyethylene layer for making the heat seal.

Finally, be sure to follow the film manufacturer's recommendations for seal width, as well as sealing temperature, pressure and dwell time.

Table 6

Recommend Packaging Films		
Product	**Description/ Use**	**Water Vapor Transmission Rate ($g/100in^2/24hrs$)**
Protect 470 Foil (OPP/PI/Foil/PE) MIL-PRF-131K	Most small to medium sized parts or stock shapes	<0.0005
Protect HD100 Foil (Biax Nylon/PE/ Foil/FE/Hvy Duty Coex) MIL-PRF-131K	Large stock shapes with sharp edges	0.0005
Protect VF191 Clear MIL-PRF-22191F	Most parts requiring see-through packaging	<0.03
Protect HD200 Clear (Biax Nylon/PE/ EVOH Coex)	Extra heavy and sharp edged parts	0.15