



POLYONICS

867 Rt 12, Westmoreland, NH 03467

Phone +1 603-352-1415 Fax +1 603-352-1936 email: [info@polyonics.com](mailto:info@polyonics.com)

Website: [www.polyonics.com](http://www.polyonics.com)

**What happens when you heat a label ?  
(More than you ever wanted to know)**

**Dr. James R. Williams, Chief Technology Officer, Polyonics, Inc.**

**INTRODUCTION**

When you change the temperature of any object, the object itself undergoes change, some physical, and some chemical. The kind of change and the extent of change depends on the temperature, and the length of time at the new temperature.

**Physical changes with changes in temperature** are easy to envision. When you heat ice (frozen water) it melts and changes into water, then to steam. Cooling the steam changes it back into liquid water, and then eventually back into ice. Many physical changes are reversible, but some are not. Thermal effects on labels tend to fall in the irreversible category.

Labels are chemical “objects” also, and undergo changes governed by these laws of thermodynamics. Usually we do not think about this until we encounter an application which requires a special label material to withstand a specific or unusual environment. Why is it that some labels work under certain thermal conditions while others do not?

**The nature of label materials**

Labels used today are generally based either on cellulosic paper, or synthetic plastic films. The telescoping of paper labels stored in a humid environment is due to the expansion of the cellulose fibers as they absorb water. Heating cellulose has the reverse effect. There are very few other physical changes due to the highly structured and interlinked nature of cellulose. Above 100 °C, chemical changes will start to occur, which we will discuss further below.

Synthetic plastic films are created from a polymer solution or a molten plastic material (see the note, “What is a polymer?”). The solution (or molten plastic) is cast or extruded uniformly onto a smooth surface. As the film forms, it is stretched to add strength and impart other physical properties, by orienting the polymeric molecules which make up the film. The terms “machine direction” and “transverse direction” (regarding tensile or tear strength of films) relates to the physical properties imparted to the film by this stretching process used during its manufacture. The film cools with its physical properties “frozen” into place, and it is rolled up to later become useful as part of a label. These films are often called “oriented” films (if stretched in one direction), or “biaxially oriented” films (if stretched in two directions).



Heating a plastic film will cause it to shrink into its original, unstressed (stretched) state, in accordance with the physical laws mentioned earlier. This phenomenon can be used to advantage, in the case of “heat-set or heat-stabilized” or so-called “high temperature” polyester films. The polyester film is heated to say 200 °C. It shrinks at a specific rate up to that temperature. Once it is cooled, it can subsequently be heated back up to (but no hotter than) 200 °C, with no additional shrinkage. But, at 201 °C it will begin to shrink again !!

Occasionally, one will observe that coated films curl as they are heated, almost always inward to the coated side. This is because the coating may be shrinking, creating an inward force causing the base film to curl, even though the temperature may be below the “shrinking point” of the film.

The thermodynamic laws state that the polymer chains want to be in a highly random and disorganized state, like a plastic “ball”. Don’t forget we forced the polymers to become a film through heating and stretching. In general, physical changes tend to be reversible, so the polymers will revert to the most stable state of disorganization, upon reheating and with no external forces applied. “Cross-linking” of polymer films will diminish the tendency of the film to shrink as it is heated. A given standard polyester film may shrink 20-30 % at 200 °C, while its cross-linked brethren may shrink less than 1 or 2 %.

Adhesives may also undergo physical change when heated. A typical pressure sensitive adhesive will have a relatively low “glass transition temperature” (see the NOTE), which means it will behave like a liquid at a lower temperature than a polymer with a higher transition temperature. Adhesives may have transition points as low as 25 – 30 °C, while films may have transitions at 100-200 °C. So adhesives behave like liquids, and “ooze”. This explains why the storage condition of labels is critical to prevent adhesive ooze. Label manufacturers are always well advised to store labels in cool, dry conditions.

The type of chemical family used in the backbone of the polymer chains has the most significant influence on the temperature resistance of the synthetic label film. Table 1 shows a listing of a wide variety of films widely used as label materials, classified by their chemical names, and a glimpse of their respective thermal behavior.



**Figure 1. Label Material Thermal Performance**

Label Material	Continuous (°C)	Short Term (°C)
Thermal paper	100	
Acrylic*	80	
Vinyl	80	
Polystyrene*	100	
Polyethylene/Polyolefin	90	
Paper	100	
Acetate*	110	176
PDF	110	190
Polycarbonate (Lexan)	110	140
Polyester	110	175
Polyamide	135	175-195
Polypropylene	149	
HT Polyester	160	200
PEN	190	210
PEI	201	232
PolyAramide	255	280
Polyimide	260	350-450

In summary, then, heating a label subjects it to physical change. The film can shrink or curl, and the adhesive can ooze. This behavior is influenced by the chemical family of the film chosen, the length or size of the polymer chain, the amount of cross-linking of the polymer, and the glass transition temperatures of each component of the label.

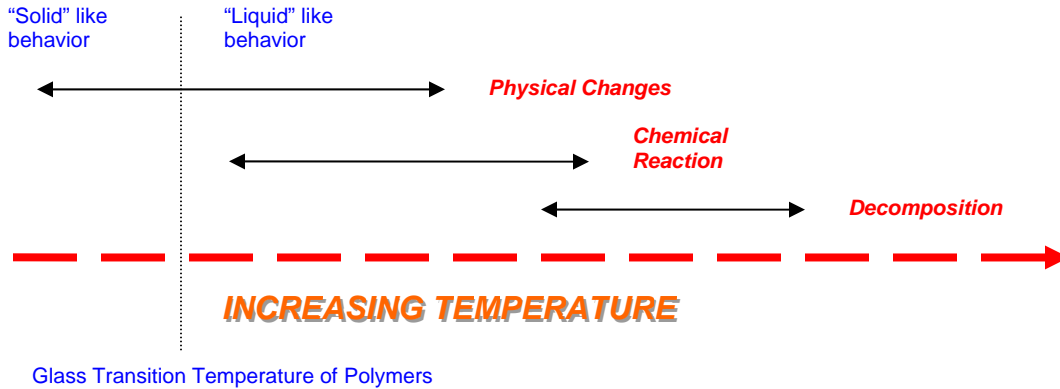
**Chemical changes** also can occur as you heat the label. Coatings, inks, and adhesives are affected as well as the films. Oftentimes label performance is enhanced by heat. The ink “sets up” and becomes impervious to chemicals and abrasion. The coating may react further, with the similar effect of enhanced physical and chemical resistance. And the adhesive may “thermoset”, as the heat causes it to cure into a hard, chemically impervious, highly cross-linked plastic. Yet, some inks, coatings, and adhesives may only undergo slight chemical reactions with no discernible performance difference between unheated and heated labels.

Eventually, if “enough” heat is applied, all labels will begin to decompose. Synthetic plastic labels as well as paper labels are based on carbon chemistry. Carbon will eventually burn in the presence of air to form carbon dioxide and water. Dozens of other decomposition reactions may occur as the temperature of the label exceeds the decomposition point of any of the components which make up the label, i.e. the film, adhesive, coating, or ink. The label may burst into



flames. It may shrivel, melt, and emit clouds of smoke. Or, in the case of certain materials, it may physically darken, emit smoke, and decompose to leave a char or deposit of ash.

**Figure 2. Summary of Effects as Labels are Heated**



Re-examination of Figure 1 suggests that there is a relationship between the temperature, and the exposure time for label suitability under various thermal conditions ('Short Term' and 'Continuous'). Chemicals undergo change, whether physical, chemical, or decomposition, exponentially proportional to the temperature. "The hotter..the faster.." is the rule of thumb. In practice, labels may be used above the theoretical decomposition temperatures, but for very short amounts of time. For example, acrylic adhesives begin to decompose at around 200 °C, yet they are widely used for bar code labels on circuit boards at temperatures in excess of 300 °C, for only a few seconds, or minutes, not hours or days.

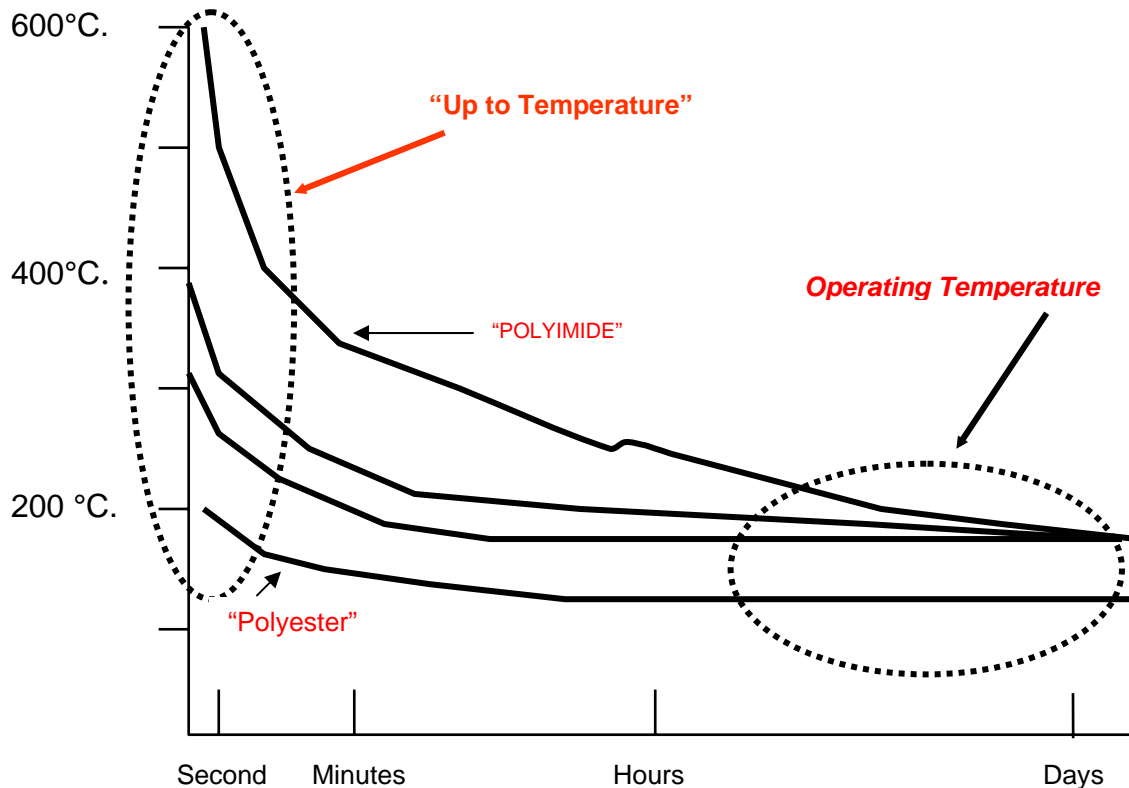
**Figure 3** depicts this time-temperature relationship commonly encountered with ALL label materials commonly used today. Labels can withstand very high temperatures, but for short periods of time, the so-called "up to" temperatures so common in marketing literature today. **BEWARE OF THIS TRAP.** The proper questions to ask are "Up to and for 'How Long' ?".

As the temperature is lowered, the useful life increases exponentially, to reach the so-called "operating temperature". Interestingly, materials which exhibit very good performance at "up to" temperatures may degrade more quickly at operating temperatures than another material which does not exhibit the same thermal behavior at the higher temperatures. In other words, different chemical reactions may occur at lower temperatures within the polymer networks. The "up



to” temperatures are good indicators of long term performance, but are not infallible. In all cases, the LAW is **test, test, and test.**

**Figure 3. Time-Temperature for Different Label Materials**  
(Not to Scale)



**Figure 4** displays the actual time-temperature performance curve for a high performance polyimide label, Polyonics XF 557. Although polyimide film may exhibit higher thermal resistance at 600 °C, other components of the label decompose at lower temperatures. The adhesive is typically acrylic, the inks contain waxes, and the coatings may be comprised of polymers that are inherently less stable than polyimide. Thus, it is the performance of the total label which is observed.

Harsh environment label requirements continue to demand labels which perform at higher temperatures, and for longer time periods. Developments must occur which increase label performance at not only the “up to” temperatures, but also increase the resistance to increasingly higher operating temperatures.



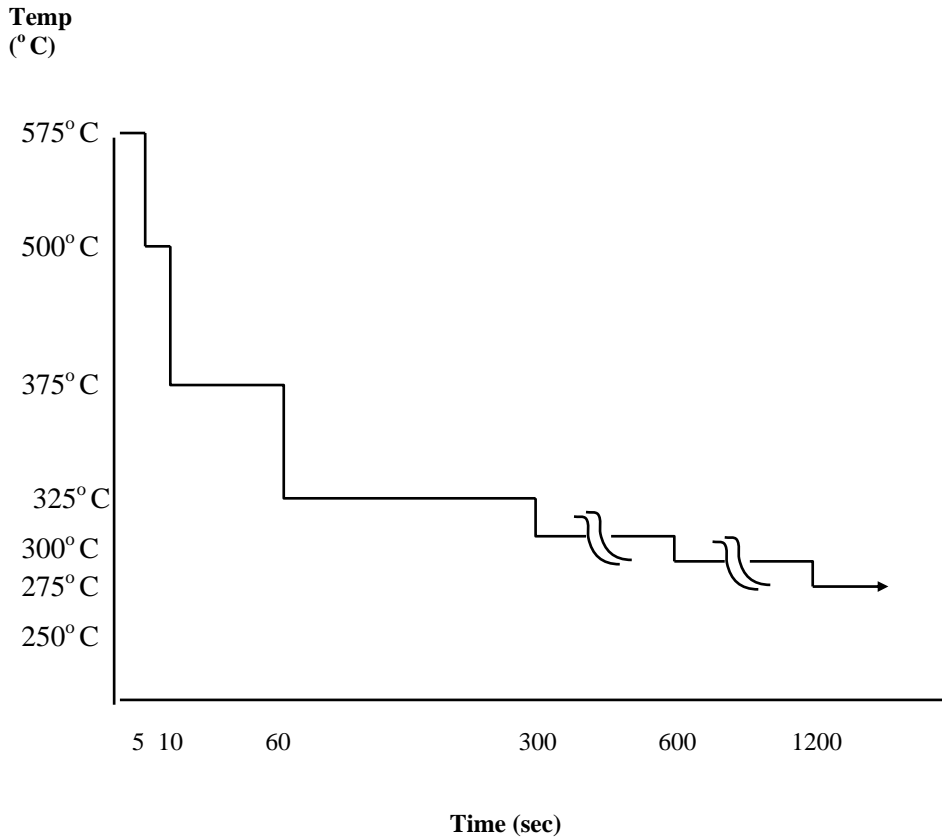
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**Figure 4. Actual Time vs. Temperature Acceptable Performance Curve  
POLYONICS XF 557, Printable Polyimide for Circuit Board Labels**



Words of caution are appropriate as each new application is analyzed for thermal performance. Oftentimes an operating temperature may only reflect the temperature of the external heat applied, and not the actual heat experienced by the label. The mass of the product may actually keep the label cooler than the external environment, because the product is absorbing the thermal energy faster than the label. Conversely, if the label is being applied to a hot product, the label may be experiencing more heat than measured by external measurement. It is important to know how much heat the label is actually experiencing. Higher thermal performance requirements generally dictate higher label costs. For example, polyimide is much more expensive than polyester, which in turn, is more expensive than paper (see Figure 5).



**Figure 5. LABELS FOR PRINTED CIRCUIT BOARDS**

Label Material	Comment	Relative Cost
Paper	Finished goods only.	1
Polyesters	Excellent for WIP and pre-solder, (non-solder side of board).	10-15
Polymeric	IR Reflow	20-30
Polyimides	General workhorse, solder side	40-60

*Increasing Process Temperature*

Proper matching of the material to the actual thermal environment can save the customer money. Improper matching of material to requirement spells disaster.

**Summary**

Labels undergo physical and chemical changes when heated. The application requirements determine whether the changes are significant. The length of time at a given temperature also influences the performance of the label material for each application. Labels can be specified to behave “up to” certain temperatures for short periods of time, and exhibit different behavior at “operating temperatures”. Label cost is directly proportional to temperature resistance and high temperature performance. Inadequate specification may result in lack of performance, while over-specification may result in unnecessary costs to the customer.

**About the author:** *Dr. James R. Williams has been involved with industrial marking and harsh environment labeling since 1977. He is the founder of Imtec, Inc., which specialized in barcode labeling equipment and harsh environment labels. He is the founder, Chairman, and Chief Technology Officer of Polyonics, Inc. a company which specializes in label and marking materials for high temperature and industrial product identification.*



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**NOTE: What is a polymer?** “Poly” means many. A polymer is a long chain composed of individual chemical fragments. For example, you have heard the names vinyl, ethylene, propylene, ester, imide, and amide. These are discrete molecules which differ in chemical structure and physical properties. So “polyethylene” means many ethylene pieces “chained” together by chemical reaction. The same for “polypropylene”, based on propylene, Polyester, polyimide, and so forth.

**CROSS-LINKING:** The individual polymer chains can also be linked together, to further change their physical and chemical properties. Think of the relationship between threads and fabric. The threads are a model for the polymer chains, while the fabric is a model for a highly cross-linked polymer. Each thread has some strength along its length, but is very dimensionally unstable. The fabric becomes not only strong due to the combination of the threads, but also dimensionally stable because of the weave, which is equivalent to cross-links. The tighter the weave is, the stronger the fabric becomes. The higher the number of cross-links in a polymer, the more physically stable the polymer. This so-called “cross-linking” is responsible for many useful products today. Polyethylene, is a very stretchy film. Yet by cross-linking it, creating a web of bridges and links between polymer chains, plastic shopping bags with very little tendency to stretch, result.

**Glass Transition Temperature:** A polymer is known as an amorphous material, both a solid, and a very viscous liquid. It has characteristics of both. The so-called “glass transition temperature” is the temperature below which a polymer shows the behavior of a solid, and above which it shows the behavior of a liquid. A polymer with a low glass transition temperature is more “liquid-like” than one with a higher glass transition temperature. Adhesives have much lower transition temperatures than do films. Consider a glass window, an example of an amorphous solid. Look through a 100 year old glass window, and you will notice that it has ripples. The top of the glass is thinner than the bottom. During its 100 years, the amorphous solid silicon dioxide has physically flowed downward due to gravitational force!!