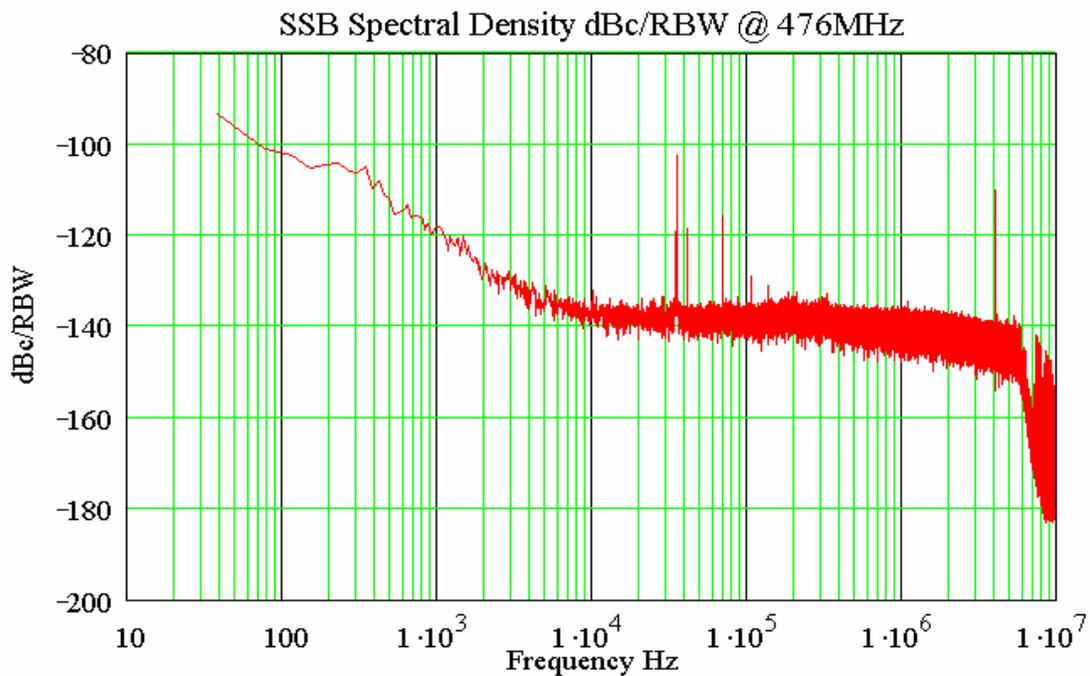


Temperature Stability of RF Components

R. Akre 4/21/2005

Typically the phase change of the RF passing through a device will change with temperature. With near speed of light cables, the cable length increases with temperature and the phase goes negative. Changes in dielectric constant with temperature will also effect the phase changes. The specification for LCLS to achieve 70fS rms error between the phase of the RF and the electron beam is not easily realizable. Some characteristics of the task and the technical approach are described in previous papers, see references. Measurements of the RF system have shown portions of the system to be stable to LCLS specifications for periods of 15 minutes. Temperature changes will drive the RF system out of tolerance beyond that. The phase of the RF which the beam sees in an accelerator structure can't be measured with a single RF measurement. The phase change through the structure is too large to measure to within LCLS tolerances. We will measure the input phase, the output phase and the temperature of the structure along with beam based parameters, energy and bunch length, to determine the phase and amplitude which the beam saw passing through the accelerator.

We have received new low noise oscillators of which one will be installed to run the 2 mile linac. One of the other oscillators will be used to measure phase noise of the components in the 2 mile linac over the next few months. This will determine which components, in the phase reference system, will need to be upgraded. The phase noise of these oscillators is shown below.



RBW = 38.147

5-11-04 File:20M 97-98CF.dat

Below is a portion of the data collected over the past few years on linac RF phase stability. The amplitude of the RF pulse specifications are easier to achieve than the phase, so the efforts are concentrated on phase stability. Changes in the amplitude will cause amplitude to phase conversion and the phase will go out of tolerance before the amplitude.

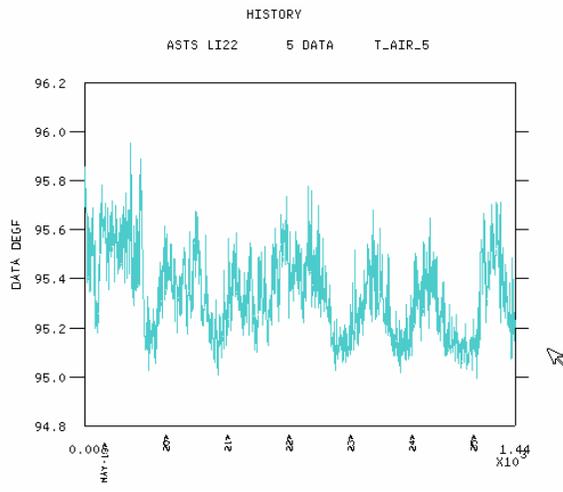
In the below data 1°S (1° at 2856MHz) = 1pS or 1000fS.

A look at temperatures in the SLAC Linac

Temperature Variations

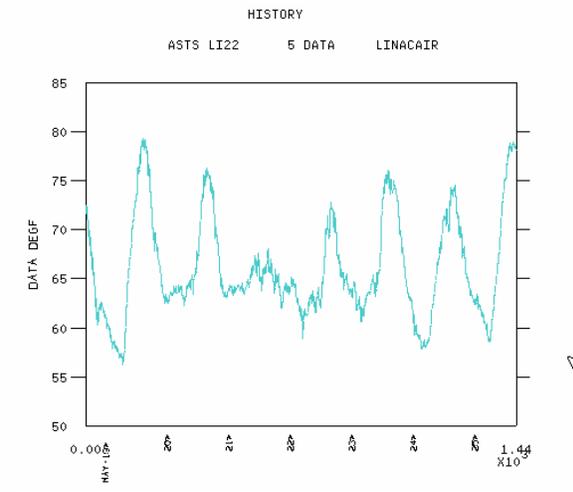
The temperatures of concern	RF devices	1 Week STD	4hours
Linac Tunnel Temperature	RF cables	0.17F	.084F
Gallery Temperature	RF Cables	5.1F	0.9F
Accelerator Water (ACC_H2O) (See Appendix A also)	Accelerator Structures	0.11F	0.052F
Waveguide Water (WG_H2O)	SLED Cavities		
	Low Level RF (Multipliers)	0.07F	0.045F

The following are plots of temperature variations over one week.



INTERVAL: 360 MEAN: 95.33747 MIN: 94.99158
 SIGMA: .1698228 MAX: 95.95081
 LAST DATA POINT: 25-MAY-2004 16:08:19 MAX-MIN: .9592285
 25-MAY-04 16:08:38

Linac Tunnel Temperature



INTERVAL: 360 MEAN: 66.07637 MIN: 56.14978
 SIGMA: 5.147911 MAX: 79.27173
 LAST DATA POINT: 25-MAY-2004 16:08:19 MAX-MIN: 23.12195
 25-MAY-04 16:09:55

Linac Gallery Temperature

LCLS Phase Errors due to Temperature Changes over 4 hours

100 ft heliax in the tunnel	$1\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.084^{\circ}\text{F} = 0.084^{\circ}\text{S}$
Accelerator Structures 10ft	$-8.6\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.052^{\circ}\text{F} = 0.45^{\circ}\text{S}$
SLED Cavities	$+8.5\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.052^{\circ}\text{F} = 0.44^{\circ}\text{S}$
1-5/8 Rigid Coax (100 meters)	$0.2\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.084^{\circ}\text{F} = 0.017^{\circ}\text{S}$
WR284 Waveguide (100 meters)	$4.6\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.045^{\circ}\text{F} = 0.21^{\circ}\text{S}$
Frequency Multipliers	$1.8\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.045^{\circ}\text{F} = 0.081^{\circ}\text{S}$
PAD (Phase and Amplitude Detector)	$0.02\text{ }^{\circ}\text{S}/^{\circ}\text{F} \times 0.045^{\circ}\text{F} = 0.0009^{\circ}\text{S}$

Most of the above temperature drifts will bring the LCLS RF system out of tolerances. Feedback must be used to control the system. Parts of the system have been shown to be stable for up to 15minutes without feedback.

References:

R. Akre, V. Bharadwaj, P. Emma, P. Krejcik, "SLAC Linac RF Performance for LCLS", SLAC-PUB-8574, and THC11, LINAC 2000, Monterey, CA, Aug. 2000

R. Akre, P. Emma, P. Krejcik, "Measurements on SLAC Linac RF System for LCLS Operation", SLAC-PUB-8820, and TPAH105, PAC 2001, Portland, OR.

APPENDIX A

Accelerator Water Temperatures SLAC Linac

The 10 foot S-band accelerator structure has a phase slip of 15.5°S/°C(1) or 8.6°S/°F. The temperature induced phase error of the RF as measured at the input of the structure or the output of the structure relative to the average phase the beam sees as it traverses the structure is ½ the above value, 4.3°S/°F. If we assume the accelerator temperature variation is the same as the accelerator water temperature variation, in order to hold the beam to RF phase to within 0.1°S the temperature variation must be no greater than 0.023°F. Sector 0, which is the most critical sector in the accelerator, would meet this requirement.

Accelerator Water Temperatures and Phase Errors due to Accelerator Structure Only

512 point data were taken with correlation plots. During the second data set, 8000 seconds or 2.2 hours, sector 21 gallery temperature increased 4.3°F.

Accelerator Water Temp	Deg F							
	512 points in 840Sec. 3/6/99 6:25		512 points in 8000Sec 3/6/99 7:00		History Buffer 1 week - end 3/6/00		STD Phase Error	
	Sector	AVG	STD	AVG	STD	AVG	STD	Deg S
0	109.5	0.020	109.5	0.024	109.5	0.043	0.19	
1	110.6	0.036	110.7	0.050	110.7	0.057	0.25	
2	110.7	0.068	110.8	0.040	110.7	0.047	0.20	
3	111.4	0.034	111.5	0.053	111.4	0.064	0.28	
4	112.1	0.042	112.1	0.048	112.1	0.059	0.25	
5	112.1	0.047	112.1	0.069	112.1	0.062	0.27	
6	112.0	0.052	112.1	0.066	112.0	0.073	0.31	
7	112.0	0.107	112.0	0.106	111.9	0.122	0.53	
8	112.0	0.084	112.1	0.095	112.0	0.106	0.46	
9	112.2	0.043	112.3	0.066	112.2	0.071	0.31	
10	111.8	0.050	111.8	0.098	111.8	0.104	0.45	
11	111.9	0.032	111.9	0.032	111.9	0.043	0.19	
12	112.1	0.045	112.1	0.049	112.1	0.063	0.27	
13	111.9	0.033	111.9	0.054	111.8	0.061	0.26	
14	111.7	0.065	111.7	0.066	111.7	0.072	0.31	
15	111.8	0.039	111.9	0.066	111.9	0.065	0.28	
16	111.9	0.045	111.9	0.058	111.9	0.067	0.29	
17	111.9	0.056	111.9	0.074	111.9	0.070	0.30	
18	111.9	0.065	112.0	0.063	111.9	0.081	0.35	
19	111.9	0.083	111.9	0.106	111.9	0.101	0.43	
20	112.2	0.073	112.1	0.076	112.1	0.066	0.28	
21	112.1	0.180	112.2	0.102	112.1	0.146	0.63	
22	111.9	0.054	112.0	0.074	111.9	0.087	0.37	
Avg	111.7	0.059	111.8	0.067	111.7	0.075	0.324	

Teflon thermal expansion: <http://www.andersonmaterials.com/tma.htm>

Thermomechanical Analysis (TMA) Thermal Analysis

- The TMA uses interchangeable probes at varied loads to make a number of measurements, including the softening temperature or glass transition temperature, tensile modulus, compression modulus, coefficient of thermal expansion (CTE), melting temperature, crystalline phase transition temperature, and crystalline to amorphous transition temperatures.
- [DSC](#) can also be used to measure glass transition temperatures, crystalline phase transition temperatures, crystalline phase transformation temperatures, and melting point temperatures.
- Samples in the form of plugs, films, powders, or fibers, are compressed or held in tension by a probe assembly. Movement of the probe is translated electrically by a linear variable differential transformer (LVDT), attached to the probe, into a signal.
- Capable of testing polymers, metals, glasses, ceramics, inorganics, composites, and semiconductors.
- Temperatures can range from -180°C to 800°C.
- Sample dimensions: a maximum of 25 mm in height and 9.5 mm in diameter; a minimum of 0.1µm thick and 1.5 mm in diameter, an ideal thickness being 1-4mm.
- The applied load can range from 0-100 g.
- The change of dimension should be greater than $2 \times 10^{-3} \mu\text{m}/^\circ\text{C}$

ASTM Standard Test Methods:

- ASTM E228 - Standard Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer
- ASTM E831 - Standard Test Method for Linear Thermal Expansion of Solid Materials by TMA
- ASTM E1545 - Standard Test Method for Assignment of the Glass Transition Temperature by TMA

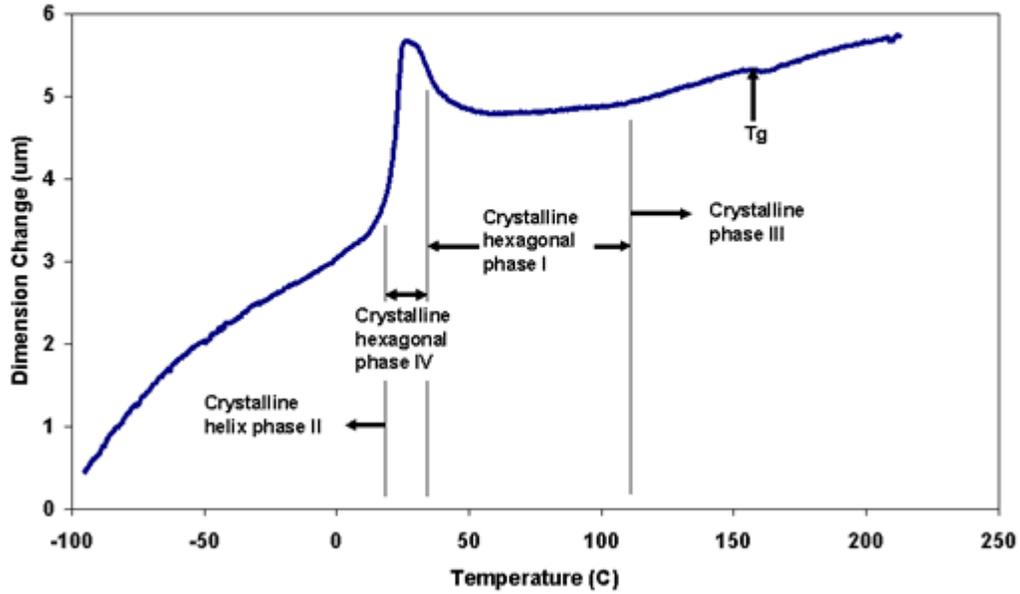
Illustrative Example: Rapid thermal expansion of PTFE crystalline phase

TMA was used to characterize the properties of various PTFE powder materials. These were examined after pressing them into sheets. The sheet thickness was measured from -100°C to 200°C using a ramp rate of 4°C/min. The first of several TEFLON[®] materials (Fig. 1) exhibits an extensive crystalline transition at approximately 19°C due to a transformation of the Phase II helix crystal structure first to the Phase IV hexagonal crystal structure and then to the Phase I hexagonal crystal structure. This large peak created at transition indicates a PTFE which has a substantial crystalline phase and exhibits a drastic dimension change as it changes the crystalline phase. Also shown by the TMA is the softening point (T_g or T_s) of the TEFLON[®] at approximately 160°C. Data for another of several samples is seen in Fig. 2. This TEFLON[®] material exhibits a significantly smaller crystalline to amorphous transition dimension increase compared to the material observed in Fig. 1. This material initially consisted of a greater concentration of amorphous material. For our customer's intended use, a rapid thermal expansion of a PTFE material at the crystalline transition temperature could not be tolerated. Their requirement was therefore for an amorphous PTFE material.

Sample: TEFLON 7A
Size: 0.7300 mm
Method: LOW TEMP TEFLON
Comment: DUPONT TEFLON 7A

TMA

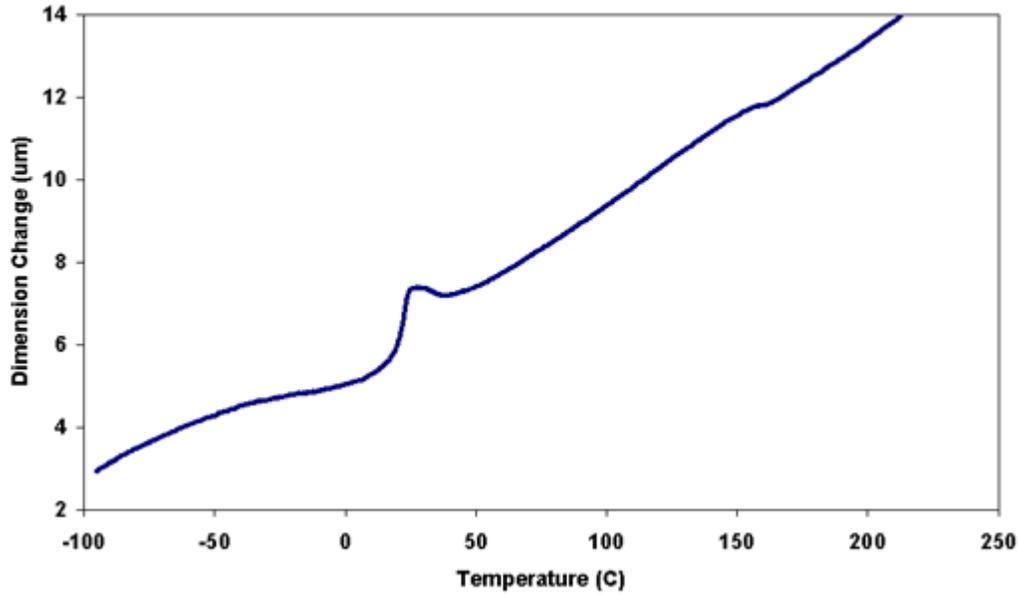
File: C:\rmx\TEFLON.006
Operator: OLEG
Run Date: 14-May-01 20:32



Sample: TEFLON 8A
Size: 0.6500 mm
Method: LOW TEMP TEFLON
Comment: DUPONT TEFLON 8A

TMA

File: C:\rmx\TEFLON.004
Operator: OLEG
Run Date: 14-May-01 16:56



Thermoplastics - An Introduction

Topics Covered

[Background](#)

[Thermoplastic Characteristics](#)

[Amorphous Polymers](#)

[Semi-Crystalline Polymers](#)

Background

What is an engineering thermoplastic? Such a definition is difficult to arrive at and is very subjective, but, for the purposes of this review article, any thermoplastic that can be formed into a load-bearing shape that might otherwise be formed from, for example, steel or wood will be classed as an engineering thermoplastic. This review is restricted to unreinforced and short fibre reinforced thermoplastics where the reinforcing fibre (usually glass or carbon) is typically less than 2-3 mm in length.

Thermoplastics offer many advantages over traditional materials, including: low density; low energy for manufacture; low processing costs; and the ability to make complex shapes relatively easily.

Thermoplastic Characteristics

Thermoplastic materials generally fall within two classes of molecular arrangement, amorphous and semi-crystalline (see figure 1).

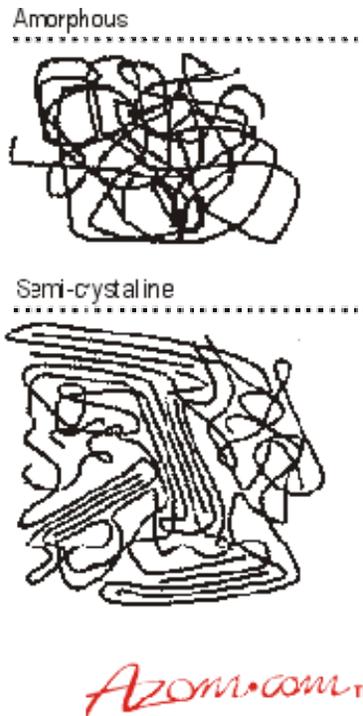


Figure Error! Bookmark not defined. Molecular Arrangement of Polymer Chains

Table 1 lists a selection of amorphous and semi-crystalline polymers.

Table 1. Amorphous and semi-crystalline polymers.

Amorphous	Semi-crystalline
Polyamideimide	Polyetheretherketone
Polyethersulphone	Polytetrafluoroethylene
Polyetherimide	Polyamide 6,6
Polyarylate	Polyamide 11
Polysulphone	Polyphenylene sulphide
Polyamide (amorphous)	Polyethylene terephthalate
Polymethylmethacrylate	Polyoxymethylene
Polyvinylchloride	Polypropylene
Acrylonitrile butadiene styrene	High Density Polyethylene
Polystyrene	Low Density Polyethylene

Amorphous Polymers

Generally, fully amorphous polymers are stiff, brittle and clear in the virgin state. The temperature and stress state have a profound effect on the molecular arrangement and hence the properties of a polymer. Under the action of sufficient stress, the polymer chains can uncoil and align over a period of time. At elevated temperatures, polymer chains have enough energy to rotate and coil up further.

Figure 2 shows schematically the effect of temperature on the elastic modulus of an amorphous and a semi-crystalline polymer. Below a temperature known as the glass

transition temperature, T_g , the structure of amorphous polymers is termed 'glassy', with a random arrangement of the polymer chains, similar to the random molecular arrangement found in glass. As the temperature increases to T_g , the polymer chains have sufficient thermal energy to rotate, resulting in a drop in modulus. One definition of T_g is the temperature at which molecular rotation about single bonds becomes favourable as the temperature increases. At temperatures above T_g but below the melting temperature, T_m , there is a 'rubbery region', where the material can exhibit large elongations under relatively low load. Amorphous thermoplastics are generally used at temperatures below their T_g , where they can be brittle, just like glass. There are, however, certain exceptions. Polycarbonate (PC) is amorphous yet it is considered tough at temperatures well below its T_g . When it does fracture below its T_g , it does so in a brittle manner, but this requires a large amount of energy and so PC is considered tough, finding use in applications requiring impact resistance, e.g. safety helmets and bullet proof glazing. This behaviour is due to the chemical bonds in polycarbonate rather than the arrangement of the polymer chains.

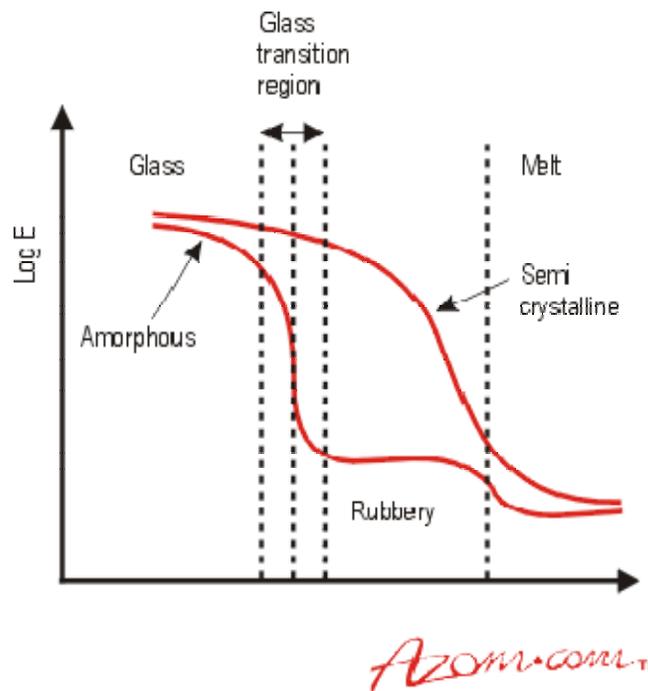


Figure 2. The effect of temperature on the Elastic Modulus (assuming both types of polymer have the same T_g and T_m)

Semi-Crystalline Polymers

Semi-crystalline materials such as polyamides do not exhibit a clear T_g or 'rubbery' region, although one is often quoted as the amorphous parts of the structure will undergo some transition. For these polymers the main transition occurs at T_m when the crystalline regions break down (see Fig. 2). Some chain rotation in the amorphous regions will occur below T_m , giving some impact resistance at these temperatures. Values of T_g and T_m for a number of polymers are given in Table 2.

Table 2. Glass transition and melting temperatures for a range of thermoplastics.

Polymer	Tg (°C)	Tm (°C)
High density polyethylene (HDPE)	-	135
Polypropylene (PP)	-10	175
Polystyrene (PS)	100	-
Polymethylmethacrylate (PMMA)	105	-
Polyvinylchloride (PVC)	65	-
Natural rubber (NR)	-75	25
Polydimethyl siloxane (PDMS)	-125	-55
Polyoxymethylene (POM)	125	175
Polycarbonate (PC)	150	-
Polyethylene terephthalate (PET)	70	265
Polyetheretherketone (PEEK)	145	335
Nylon 6 (PA6)	50	215
Polyamideimide (PAI)	295	-
Polysulphone (PSul)	195	-
Polyphenylene sulphide (PPS)	90	285
Polyethersulphone (PES)	230	-
Polyetherimide (PEI)	218	-
Polytetrafluoroethylene (PTFE)	20	325
Liquid crystal polymer (LCP)	-	420

Table 2. Values of Tg and Tm for selected polymers

Abstracted From the Materials Information Service, edited by Justin Furness

For more information on Materials Information Service please visit [The Institute of Materials](#)