Coefficient of Linear Thermal Expansion

What happens when material is heated?

Under the effects of increasing temperature any material will expand. This can lead to significant changes in dimensions, to part warpage or to internal stress.

The **Coefficient of Linear Thermal Expansion** (CLTE often referred to as "α") is a material property which characterizes the ability of a plastic to expand under the effect of temperature elevation. It tells you how much the developed part will remain dimensionally stable under temperature variations.

The linear coefficient **'CLTE or α' for plastic and polymer materials** is calculated as:

$$\alpha = \Delta L / (L_0 * \Delta T)$$

Where:

- α is coefficient of linear thermal expansion per degree Celsius
- ΔL is change in length of test specimen due to heating or to cooling
- L_0 is the original length of specimen at room temperature
- ΔT is temperature change, °C, during test

Therefore, α is obtained by dividing the linear expansion per unit length by the change in temperature. *When reporting the mean coefficient of thermal expansion, the temperature ranges must be specified.*

Applications include:

The thermal expansion difference develops internal stresses and stress concentrations in the polymer, which allows premature failure to occur. Hence, CLTE is important for the economics of production as well as the **quality and functioning of products**.

- It is required for design purposes. Thermal expansion is often used to predict shrinkage in injection molded parts
- It helps determine dimensional behavior of structures subject to temperature

changes

- It also determines thermal stresses that can occur, and cause failure of a solid artifact composed of different materials when it is subjected to a temperature excursion (specially to predict **efficient material bonding** or while using plastics with metals)

Check out more on Linear Coefficient of Thermal Expansion:

» CTE, Linear Values of Several Plastics
» Main Techniques Used to Measure CTE, Linear
» Factors Affecting Thermal Expansion Coefficient Measurements

How to Measure Coefficient of Linear Thermal Expansion?

Most widely used standards to measure coefficient of linear thermal expansion in plastics (thermoplastics and **thermosetting materials**, filled or unfilled, in the form of sheet or molded parts) are ASTM D696, ASTM E831, ASTM E228 and ISO 11359.

The main techniques used for CTE measurements are:

- Dilatometry
- Interferometry and
- Thermomechanical analysis

(of course there exist several other methods as well, but they are not discussed here).

Dilatometry Technique

It is the widely used technique in which specimen is heated in a furnace and displacement of the ends of the specimen are transmitted to a sensor by means of push rod. Push rods may be of the vitreous silica type, the high-purity alumina type, or the isotropic graphite type.

ASTM D696 - This test method covers determination of the coefficient of linear thermal expansion for plastic materials having coefficients of expansion greater than 1 µm/(m.°C) by use of a vitreous silica dilatometer. The nature of most plastics and the construction of the dilatometer make −30 to +30°C (−22°F to +86°F) a convenient temperature range for linear thermal expansion measurements of plastics. This range covers the temperatures in which plastics are most commonly used.

ASTM E228 - This test method shall be used for temperatures other than −30°C to 30°C to determine linear thermal expansion of solid materials with a push-rod dilatometer

Thermomechanical Analysis (TMA)

The measurements are made using a thermomechanical analyzer consisting of a specimen holder and a probe that transmits changes in length to a transducer that translates movements of the probe into an electrical signal.

ASTM E831 (and ISO 11359-2) – These methods are applicable applicable to solid materials that exhibit sufficient rigidity over the test temperature range. The lower limit for CTE with this method is 5×10^{-6}/K (2.8×10^{-6}/°F), but it may be used at lower or negative expansion levels with decreased accuracy and precision. It is applicable to the temperature range from −120 to 900°C. The temperature range may be extended depending upon the instrumentation and calibration materials used.

Interferometry

With optical interference techniques, displacement of the specimen ends is measured in terms of the number of wavelengths of monochromatic light. Precision is significantly greater than with dilatometry, but because the technique relies on the optical reflectance of the specimen surface, interferometry is not used much above 700 °C (1290 °F).

ASTM E289 provides a standard method for linear thermal expansion of rigid solids with interferometry that is applicable from –150 to 700 °C (–240 to 1290 °F). It is is more applicable to materials having low or negative CTE in the range of $<5 \times 10^{-6}$/K (2.8×10^{-6}/°F) or where only limited lengths of thickness of other higher expansion coefficient materials are available.

Factors Affecting Thermal Expansion Coefficient Measurements of Plastics

1. Fibers and other fillers significantly reduce thermal expansion. The degree of anisotropy of the filler and the filler orientation pose great impact on the

linear coefficient of thermal expansion

2. W.r.t the temperature, the magnitude of the CTE increases with rising temperature
3. Molecular orientation also affects the thermal expansion of plastics. The thermal expansion is often affected by the cooling time during processing. This is especially true with **semi-crystalline polymers** whose crystallization process requires time

Linear Coefficient of Thermal Expansion Values of Several Plastics

The Coefficient of Linear Thermal Expansion (Or Linear Coefficient of Thermal Expansion) lies between (in the service temperature range for each case):

- Ca. 0.6×10^{-4} to 2.3×10^{-4} K^{-1} for most of the thermoplastics
- Ca. 0.2×10^{-4} to 0.6×10^{-4} K^{-1} for thermosets

Polymer Name	Min Value (10^{-5} /°C)	Max Value (10^{-5} /°C)
ABS - Acrylonitrile Butadiene Styrene	7.00	15.00
ABS Flame Retardant	6.00	9.00
ABS High Heat	6.00	10.00
ABS High Impact	6.00	13.00
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	4.00	5.00
ABS/PC Blend 20% Glass Fiber	1.80	2.00
ABS/PC Flame Retardant	3.00	4.00
ASA - Acrylonitrile Styrene Acrylate	6.00	11.00
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	7.00	9.00
ASA/PC Flame Retardant	7.00	8.00
ASA/PVC Blend - Acrylonitrile Styrene Acrylate/Polyvinyl Chloride Blend	0.00	9.00
CA - Cellulose Acetate	8.00	18.00

CAB - Cellulose Acetate Butyrate	10.00	17.00
Celllulose Diacetate- Pearlescent Films	2.15	2.15
Celllulose Diacetate-Gloss Film	2.15	2.15
Celllulose Diacetate-Integuard Films	1.00	1.50
Celllulose Diacetate-Matt Film	2.15	2.15
Cellulose Diacetate -Window Patch Film (Food Grade)	2.15	2.15
Cellulose Diacetate-Clarefiect metallized film	1.50	1.50
Cellulose diacetate-Flame retardant Film	0.64	0.64
Cellulose Diacetate-High Slip Film	2.15	2.15
Cellulose Diacetate-High Slip Film	2.15	2.15
CP - Cellulose Proprionate	10.00	17.00
COC - Cyclic Olefin Copolymer	6.00	7.00
CPVC - Chlorinated Polyvinyl Chloride	6.00	8.00
ECTFE	6.00	9.00
EVA - Ethylene Vinyl Acetate	16.00	20.00
FEP - Fluorinated Ethylene Propylene	8.00	10.00
HDPE - High Density Polyethylene	6.00	11.00
HIPS - High Impact Polystyrene	5.00	20.00
HIPS Flame Retardant V0	5.00	15.00
Ionomer (Ethylene-Methyl Acrylate Copolymer)	10.00	17.00
LCP - Liquid Crystal Polymer	0.30	7.00
LCP Carbon Fiber-reinforced	0.10	6.00
LCP Glass Fiber-reinforced	0.10	6.00
LCP Mineral-filled	0.90	8.00

LDPE - Low Density Polyethylene	10.00	20.00
MABS (Transparent Acrylonitrile Butadiene Styrene)	8.00	11.00
PA 11 - (Polyamide 11) 30% Glass fiber reinforced	3.00	15.00
PA 11, Conductive	9.00	15.00
PA 11, Flexible	9.00	15.00
PA 11, Rigid	9.00	15.00
PA 12 (Polyamide 12), Conductive	9.00	15.00
PA 12, Fiber-reinforced	9.00	15.00
PA 12, Flexible	9.00	15.00
PA 12, Glass Filled	9.00	15.00
PA 12, Rigid	9.00	15.00
PA 46, 30% Glass Fiber	2.00	2.00
PA 6 - Polyamide 6	5.00	12.00
PA 6-10 - Polyamide 6-10	6.00	10.00
PA 66 - Polyamide 6-6	5.00	14.00
PA 66, 30% Glass Fiber	2.00	3.00
PA 66, 30% Mineral filled	4.00	5.00
PA 66, Impact Modified, 15-30% Glass Fiber	2.00	3.00
PA 66, Impact Modified	5.00	14.00
PAI - Polyamide-Imide	3.00	4.00
PAI, 30% Glass Fiber	1.00	2.00
PAI, Low Friction	2.00	3.00
PAN - Polyacrylonitrile	6.00	7.00
PAR - Polyarylate	5.00	8.00

PARA (Polyarylamide), 30-60% glass fiber	1.40	1.80
PBT - Polybutylene Terephthalate	6.00	10.00
PBT, 30% Glass Fiber	2.00	5.00
PC (Polycarbonate) 20-40% Glass Fiber	2.00	4.00
PC (Polycarbonate) 20-40% Glass Fiber Flame Retardant	2.00	4.00
PC - Polycarbonate, high heat	7.00	9.00
PCL - Polycaprolactone	16.00	17.00
PCTFE - Polymonochlorotrifluoroethylene	4.00	7.00
PE - Polyethylene 30% Glass Fiber	5.00	5.00
PEEK - Polyetheretherketone	4.70	10.80
PEEK 30% Carbon Fiber-reinforced	1.50	1.50
PEEK 30% Glass Fiber-reinforced	1.50	2.20
PEI - Polyetherimide	5.00	6.00
PEI, 30% Glass Fiber-reinforced	2.00	2.00
PEI, Mineral Filled	2.00	5.00
PEKK (Polyetherketoneketone), Low Cristallinity Grade	77.00	77.00
PESU - Polyethersulfone	5.00	6.00
PESU 10-30% glass fiber	2.00	3.00
PET - Polyethylene Terephthalate	6.00	8.00
PET, 30% Glass Fiber-reinforced	2.00	5.00
PET, 30/35% Glass Fiber-reinforced, Impact Modified	1.50	2.00
PETG - Polyethylene Terephthalate Glycol	8.00	8.00
PFA - Perfluoroalkoxy	8.00	12.00

PI - Polyimide	5.50	5.50
PLA - Polylactide	8.50	8.50
PMMA - Polymethylmethacrylate/Acrylic	5.00	9.00
PMMA (Acrylic) High Heat	4.00	9.00
PMMA (Acrylic) Impact Modified	5.00	9.00
POM - Polyoxymethylene (Acetal)	10.00	15.00
POM (Acetal) Impact Modified	12.00	13.00
POM (Acetal) Low Friction	10.00	12.00
POM (Acetal) Mineral Filled	8.00	9.00
PP - Polypropylene 10-20% Glass Fiber	4.00	7.00
PP, 10-40% Mineral Filled	3.00	6.00
PP, 10-40% Talc Filled	4.00	8.00
PP, 30-40% Glass Fiber-reinforced	2.00	3.00
PP (Polypropylene) Copolymer	7.00	17.00
PP (Polypropylene) Homopolymer	6.00	17.00
PP, Impact Modified	7.00	17.00
PPA - Polyphthalamide	5.40	5.40
PPA, 30% Mineral-filled	7.10	7.20
PPA, 33% Glass Fiber-reinforced	1.00	1.20
PPA, 33% Glass Fiber-reinforced – High Flow	0.90	1.10
PPA, 45% Glass Fiber-reinforced	0.73	0.75
PPE - Polyphenylene Ether	3.00	7.00
PPE, 30% Glass Fiber-reinforced	1.50	2.50
PPE, Flame Retardant	3.00	7.00
PPE, Impact Modified	4.00	8.00

PPE, Mineral Filled	2.00	5.00
PPS - Polyphenylene Sulfide	3.00	5.00
PPS, 20-30% Glass Fiber-reinforced	1.00	4.00
PPS, 40% Glass Fiber-reinforced	1.00	3.00
PPS, Conductive	1.00	9.00
PPS, Glass fiber & Mineral-filled	1.00	2.00
PS (Polystyrene) 30% glass fiber	3.50	3.50
PS (Polystyrene) Crystal	5.00	8.00
PS, High Heat	6.00	8.00
PSU - Polysulfone	5.00	6.00
PSU, 30% Glass fiber-reinforced	2.00	3.00
PSU Mineral Filled	3.00	4.00
PTFE - Polytetrafluoroethylene	7.00	20.00
PTFE, 25% Glass Fiber-reinforced	7.00	10.00
PVC (Polyvinyl Chloride), 20% Glass Fiber-reinforced	2.00	4.00
PVC, Plasticized	5.00	20.00
PVC, Plasticized Filled	7.00	25.00
PVC Rigid	5.00	18.00
PVDC - Polyvinylidene Chloride	10.00	20.00
PVDF - Polyvinylidene Fluoride	8.00	15.00
SAN - Styrene Acrylonitrile	6.00	8.00
SAN, 20% Glass Fiber-reinforced	2.00	4.00
SMA - Styrene Maleic Anhydride	7.00	8.00
SMA, 20% Glass Fiber-reinforced	2.00	4.00
SMA, Flame Retardant V0	2.00	6.00

SRP - Self-reinforced Polyphenylene	3.00	3.00
UHMWPE - Ultra High Molecular Weight Polyethylene	13.00	20.00
XLPE - Crosslinked Polyethylene	10.00	10.00